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Short communication

An active micro-direct methanol fuel cell with self-circulation of fuel and built-in removal of CO_2 bubbles☆

Dennis Desheng Meng*, C.J. Kim

Mechanical and Aerospace Engineering Department, University of California, Los Angeles (UCLA), 420 Westwood Plaza, Los Angeles, CA 90095-1597, USA

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ABSTRACT

As an alternative or supplement to small batteries, the much-anticipated micro-direct methanol fuel cell (μDMFC) faces several key technical issues such as methanol crossover, reactant delivery, and byproduct release. This paper addresses two of the issues, removal of CO_2 bubbles and delivery of methanol fuel, in a non-prohibitive way for system miniaturization. A recently reported bubble-driven pumping mechanism is applied to develop active μDMFCs free of an ancillary pump or a gas separator. The intrinsically generated CO_2 bubbles in the anodic microchannels are used to pump and circulate the liquid fuel before being promptly removed as a part of the pumping mechanism. Without a discrete liquid pump or gas separator, the widely known packaging penalty incurred within many micro-fuel-cell systems can be alleviated so that the system's power/energy density does not decrease dramatically as a result of miniaturization. Since the power required for pumping is provided by the byproduct of the fuel cell reaction, the parasitic power loss due to an external pump is also eliminated. The fuel circulation is visually confirmed, and the effectiveness for fuel cell applications is verified during continuous operation of a μDMFC for over 70 min with 1.2 mL of 2 M methanol. The same device was shown to operate for only 5 min if the pumping mechanism is disabled by blocking the gas venting membrane. Methanol consumption while utilizing the reported self-circulation mechanism is estimated to be 46%. Different from common pump-free fuel delivery approaches, the reported mechanism delivers the fuel actively and is independent of gravity.

1. Introduction

Because of their superior energy density, micro-direct methanol fuel cells (μDMFCs) are considered as a promising power supply for extending the operation time of portable electronics, remote sensors, and autonomous devices. Despite significant recent advancements, the development of μDMFCs has encountered serious challenges in system miniaturization. For example, within a limited space, it is difficult to accommodate all the essential components, such as the fuel delivery system, phase separator, membrane electrode assembly (MEA), interconnection components, and system housing. Also, the conventional way to remove CO_2 gas bubbles from small fuel cells is to pump them, together with the fuel, to a downstream open tank. Thus, the gas is separated from liquid by buoyancy and released to the environment. Such a separation method is orientation-dependent and subjected to liquid leakage in portable devices. The CO_2 gas bubbles cause serious clogging problems in μDMFCs [1], due to the scaling-enhanced surface tension force in the anodic microchannel. Once the microchannel of a μDMFC is blocked, the effective mass-transfer area is reduced and the cell performance will decline [2]. Therefore, parasitic power needed for the pump to remove the bubbles is relatively high. Moreover, generation of gas bubbles in the sealed anodic microchannels may elevate the pressure significantly and increase detrimental methanol crossover [3]. Existing lateral venting approaches to remove gas bubbles from microfluidic devices [4,5] are prone to leakage when the medium is methanol, especially under pressure fluctuation during operation. This problem may be addressed by employing a thin polymer membrane to allow gas diffusion [6] or designing microchannel of specific geometries to temporarily alleviate the bubble clogging [7,8]. However, producing a sufficiently high removal rate of the continuously generated gas bubbles, for a fuel cell under high loads, presents serious technical challenges.

In terms of fuel delivery, various micropumps [9–11] have been proposed to actively and precisely deliver methanol fuel for μDMFCs. However, the discrete pump is a significant source of packaging penalty for the miniaturization of fuel cells, not to mention the loss of power to run the pump. Pressurized fuel cartridges [12,13] can help deliver the fuel without power-consuming com-

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* Corresponding author. Current address: Mechanical Engineering - Engineering Mechanics Department, Michigan Technological University, 815 R.L. Smith Building, 1400 Townsend Drive, Houghton, MI 49931, USA. Tel.: +1 906 4873551.
E-mail address: dmeng@mtu.edu (D.D. Meng).

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