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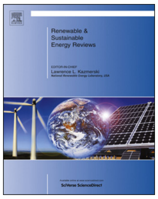

Review on micro-direct methanol fuel cells

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ABSTRACT

Fuel cells have unique technological attributes: efficiency, minimization of moving parts and low emissions. The Direct Methanol Fuel Cell (DMFC) has attracted much attention due to its potential applications as a power source for transportation and portable electronic devices. With the advance of micromachining technologies, miniaturization of power sources became one of the trends of evolution of research in this area. Based on the advantages of the scaling laws, miniaturization promises higher efficiency and performance of power generating devices, so, MicroDMFC is an emergent technology. There has been a growing interest in the development of this type of micro cells in the last years, resulting both in experimental studies (operating conditions, cell design and new materials) and in modeling studies. Despite the increase in the knowledge acquired, many challenges are still to be reached. This paper provides a detailed comprehensive review both on fundamental and technological aspects of micro-direct methanol fuel cells. Special attention is devoted to systematization of published results on experimental area since to date and also to a special section dedicated to modeling studies.

Contents

1. Introduction

Nowadays, consumers demand for portable, power-hungry devices (3G-cellular phones, laptop computers and internet-enabled PDAs) has stimulated researchers and industry to develop

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advanced miniaturized portable fuel cells to overcome systematic limitations of conventional batteries [1–4]. Medicine is also a demanding field for miniature fuel cells as implantable micro-power sources [5]. Micro-fuel cells can compete with batteries in the low power range (0–30 W). The Proton exchange membrane (PEM) fuel cell and in particular the Direct methanol fuel cell (DMFC) have potential to meet these requirements. Mostly due to the lack of effective miniaturized hydrogen storage technologies, a liquid fuel like methanol is the best option to achieve a high power density with an attractive cost-to-power ratio. MicroDMFCs can operate at room temperature reducing the thermal management challenges for small systems. Small DMFCs with various degrees of microfabrication have been reported [6]. Recently, several companies such as Toshiba, Hitachi, Fujitzu, Samsung and IBM have registered significant developments on DMFC's for portable applications.

The central part of the MicroDMFC is the proton exchange membrane. Methanol crossover is one of the most important problems to solve. High methanol concentration provides achievable energy density but it also causes severe methanol crossover through the membrane resulting in a mix potential at the cathode, lowering cell performance. Concerning the different concepts of fuel delivery and handling, the MicroFCs are categorized as passive and active [7]. An active system needs moving parts to feed oxidant or fuel to the cell requiring power to operate. A passive system requires no external power (no need of auxiliary liquid pumps and gas blower/compressor) relying on diffusion and natural convection to deliver the fuel and oxygen. There are also cells that need a dispositive to supply the fuel but are passive at the cathode side, i.e., working in air-breathing operation. Most of the works on MicroFCs rely on active systems but there is an increasing interest in the passive cells exhibiting higher volumetric energy density and more design flexibility mainly when miniaturization is needed.

The channel design determines the flow distribution in MicroFCs. Cha [8] used numerical simulation to compare the performance of several designs. The design optimization demands for a better understanding of the flow dynamics. The control of the multiphase flows at the micro scale is a crucial issue. The CO_2 bubbles formed at the anode can disturb and, eventually, block the flow. Understanding how the drops affect the flow resistance in the cathode channels is essential to develop air breathing operation. On the cathode side the water produced is injected into the channels in active systems and the developed two-phase flow plays a central role in fuel cell water management [9]. The channels must be designed for low pressure drop to avoid excessive parasitic power losses and must operate in a regime adequate to maintain a proper overall water balance. Despite the importance of water management in determining the MicroFC performance, no detailed design optimization has been reported. Numerical simulation [7,9–12] works help the optimization of MicroDMFCs.

In the last years advances have been made in the MicroDMFC research and some review papers on this type of fuel cell are available, each one focusing on different aspects of this type of cells. Morse et al. published a review [13] that presents a discussion of micro-fuel cell technologies, providing insight into the innovations that have been made until 2007. Nguyen et al. [14] reviewed recent progress of the development of micro machined membrane fuel cells (MicroPEMFC and MicroDMFC). This review first discusses the scaling law applied to this type of fuel cell. Kundu et al. [5] discussed the status on the research and development of micro-fuel cell, namely Micro-reformed hydrogen fuel cell, hydrogen fed micro-fuel cell, MicroDMFC and Micro-direct formic acid fuel cell and their commercialization status were also reported. The different substrate materials used in micro-fuel cells for the suitability of the portable electronics have also been stated. The design aspects of micro-fuel cells and micro-reformers were also discussed. Kamarudin et al. [6] presented a review that discusses the challenges and development of MicroDMFC. Besides that, the paper also shows some marketing prediction in term of economics view. The most recent review [15] from Sundarrajan et al. focused only on micro-direct methanol fuel cells is a quite detailed review on the experimental field, although there is a lack of information on modeling area.

In this paper the most recent work done on Micro-methanol fuel cells has been reviewed. Design considerations (i.e. carrier subtract, proton exchange membrane, cell design, fuel and oxidant delivery system and flowfield effect) for MicroDMFC are presented. Operating conditions used in the works reviewed are summarized and the effect of each one on fuel cell performance is discussed. The performance of the MicroDMFC reviewed are compared and discussed. The main innovations are described in a separate section. Special emphasis is devoted to the modeling studies, since there is a lack of review information on this topic.

2. Design considerations

2.1. Carrier substrate

Two approaches are normally followed when designing fuel cells: scaling down of fuel cell system using conventional assembling methods or redesign every component using microelectromechanical system (MEMS) technology. With the conventional method a fuel cell is fabricated by hot-pressing the sandwich structure of gas diffusion layer, electrodes and electrolyte membrane. For MEM systems, silicon has been widely used as the carrier substrate. These MEMS enables notably mass fabrication at low cost (very large number of devices on a very small area), which could lead to a reduction in the global cost of miniature fuel cells [16]. The most common used silicon-based micromachining techniques are [14] deep reactive ion etching (DRIE), deposition of various materials using chemical vapor deposition (CVD) and physical vapor deposition (PVD). These techniques enable miniaturization of the fuel/oxidant delivery system and the deposition of electrodes and electrode materials. Stainless steel is another

Table 1
Comparison between the various types of substrates/fabrication techniques used on micro-methanol fuel cells.

Type of substrate	Fabrication techniques	Advantages	Disadvantages
Silicon	DRIE, CVD and PVD	High temperature resistance, facilitate the possible integration of the FCs with other electronic devices on the same chip	Fragility of silicon leads to difficulties in compressing the cell for good packaging, high cell contact resistance, low conductivity
Stainless steel	Etching, laser machining or punching	High conductivity and high mechanical strength	High cost for machining, possibility of corrosion
Polymers	Polymeric surface micromachining, hot embossing, soft lithography and laser machining	Good chemical stability, light weight and low cost	Low power density obtained and major possibility of leakages between substrate and membrane