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35-We polymer electrolyte membrane fuel cell system for notebook computer using a compact fuel processor

In-Hyuk Son[a,*], Woo-Cheol Shin[a], Yong-Kul Lee[b], Sung-Chul Lee[a], Jin-Gu Ahn[a], Sang-Il Han[a], Ho-Jin kweon[a], Ju-Yong Kim[a], Moon-Chan Kim[c], Jun-Yong Park[a,**]

[a] Energy 1 Group, Energy Laboratory at Corporate R&D Center in Samsung SDI Co., Ltd., 575, Shin-dong, Yeongtong-gu, Suwon-si, Gyeonggi-do 443-731, Republic of Korea
[b] Department of Chemical Engineering, Dankook University, Youngin 448-701, Republic of Korea
[c] Department of Environmental Engineering, Chongju University, Chongju 360-764, Republic of Korea

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ABSTRACT

A polymer electrolyte membrane fuel cell (PEMFC) system is developed to power a notebook computer. The system consists of a compact methanol-reforming system with a CO preferential oxidation unit, a 16-cell PEMFC stack, and a control unit for the management of the system with a d.c.–d.c. converter. The compact fuel-processor system (260 cm^3) generates about 1.2 L min^{-1} of reformate, which corresponds to 35 We, with a low CO concentration (<30 ppm, typically 0 ppm), and is thus proven to be capable of being targetted at notebook computers.

1. Introduction

Fast-developing technologies related to electronic devices, such as cellular phones, computers, camcorders, and cordless tools, have led to an increase in the demand for high-performance energy sources. Currently, rechargeable batteries are the major players in the market for powering hand-held devices. Nevertheless, as energy demands increase with the popularization of broadband-mobile computing and an ever-increasing number of functions, existing battery technology has come up against the need for new energy-providing devices such as mobile fuel cells.

Some of the promising fuel cell technologies for portable applications are liquid–fed direct methanol-fuel cells (DMFCs) and polymer electrolyte membrane fuel cells (PEMFCs), which have a low operating temperature and fast start-up, consequently targeting high-performance notebook computer systems that usually require higher specific energy. The DMFCs have lower power densities than PEMFCs and suffer the problems of methanol crossover and slow methanol electrocatalysis [1]. Thus, PEMFCs are preferred more than DMFCs for the portable applications.

Polymer electrolyte membrane fuel cells provide an attractive alternative to conventional batteries over a wide range of power and energy capacities. The advantages of using PEMFCs are high electrical efficiency, flexibility with respect to power and capacity, long lifetime, and good ecological impact [2,3].

Hydrogen is the best fuel for fuel cells. For notebook computer applications, the hydrogen-supply units should be compact with high specific energy. Metal hydrides, chemical hydrides and fuel reformers are candidates for hydrogen-supply. A compact micro-fuel reformer is particularly attractive because of its high specific energy and capability for instant recharging of fuel [4]. Nevertheless, fuel-reformer technology has become a bottleneck for the practical use of fuel cells.

Hydrogen for PEMFCs can be produced in an on-board fuel processor from a liquid fuel such as methanol or gasoline. Although the term 'reformer' is often used for the whole system, the production of hydrogen actually occurs via three processes, as follows.

(1) the *autothermal reforming* of a hydrocarbon, i.e.,

$$\text{fuel} + O_2 + H_2O \rightarrow CO_X + H_2 \tag{1}$$

wherein partial oxidation and steam reforming (SR) take place in the absence of water and oxygen, respectively;

* Corresponding author. Tel.: +82 31 210 7318; fax: +82 31 210 7374.
** Corresponding author. Tel.: +82 31 210 7806; fax: +82 31 210 7374.
E-mail addresses: Inhyuk74@daum.net (I.-H. Son), woocheol.shin@samsung.com (W.-C. Shin), yongkul.lee@samsung.com (Y.-K. Lee), sungchul01.lee@samsung.com (S.-C. Lee), jg.ahn@samsung.com (J.-G. Ahn), sangil.han@samsung.com (S.-I. Han), hojin.kweon@samsung.com (H.-J. kweon), juyong.j.kim@samsung.com (J.-Y. Kim), mckim@cju.ac.kr (M.-C. Kim), jy3000.park@samsung.com (J.-Y. Park).

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(2) the water–gas shift reaction, which eliminates most of the CO and produces more hydrogen, i.e.,

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (2)$$

(3) preferential oxidation (PROX) to decrease any remaining CO to ppm level [3].

$$CO + O \rightarrow CO_2 \quad (3)$$

The PROX reaction is a selective catalytic oxidation of CO in the H_2-rich reformate using O_2 as an oxidant. Many auxiliary processes, such as fuel vapourization, sulfur removal, heat integration and effluent-gas combustion, can make PEMFC a very complicated device. To apply the fuel cell system to a notebook computer, the fuel system should be miniaturized and integrated within the system.

For powering a notebook-computer system, Samsung SDI Co. is in the process of developing a 50-We PEMFC for its continuous use (more than 10 h) on a single fuel cartridge using methanol as a fuel source (targets: >150 mW cm^{-2} power density; >600 Wh L^{-1} energy density; <500 g weight; <930 cm^3 volume).

As a milestone, a 35-We PEMFC has been contracted and a continuous durability test lasting 24 h is reported here. Hydrogen with a low CO level (<30 ppm, *typically* 0 ppm) is supplied using a compact methanol-reforming fuel processor, which includes a catalytic combustor, a methanol steam reformer, and a CO preferential oxidation reactor.

This study addresses the characteristics of the fuel cell–power system in terms of the design and performance of the fuel processor, which powers, the 35-We PEMFC that possesses the capability for carrying out various operations in a commercial notebook computer. The results from the durability test assure the reliable performance of the system in terms of the power output for within-the-range gas compositions.

2. System design

The 35-We PEMFC system for powering a notebook computer consisted of three parts, namely: fuel processor, stack and process controller. A schematic representation of the system for a notebook computer is shown in Fig. 1 and its three-dimensional graphic (3500 cm^3) representation is presented in Fig. 2.

The fuel cell power system operates at ambient temperature. The methanol-reforming system supplies hydrogen to the stack after reducing the CO content with a PROX system. The electrical power generated by the stack from the hydrogen and air fed from a pump is supplied to a notebook computer. A control unit regulates the air-flow rate and the methanol-fuel pressure during the entire operation and conducts a controlled start-up and shut-down of the fuel cell and power converter.

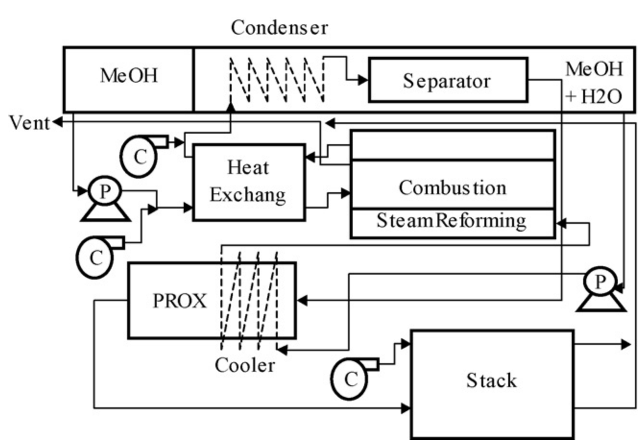

Fig. 1. Schematic diagram of 35-We PEM fuel cell system for notebook computer.

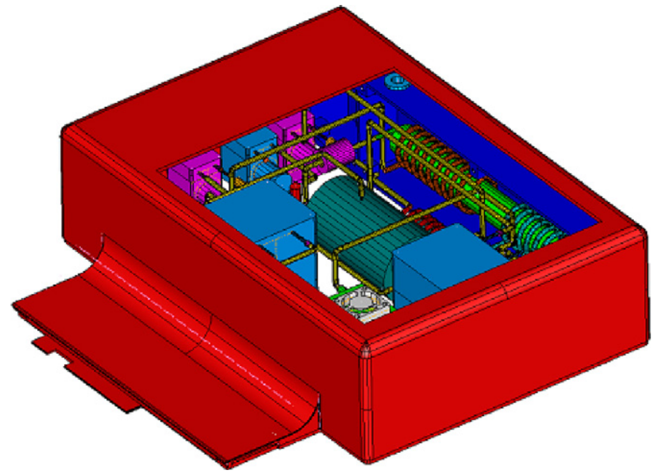

Fig. 2. Three-dimensional graphic presentation of 35-We PEM fuel cell system for notebook computer.

2.1. Fuel-process system

A compact methanol-fuel process for a 35-We PEMFC for a notebook computer consists of a reformer with a catalytic combustor and a carbon monoxide catalytic reducer. The reformer, in turn, consists of an inner combustion-reaction unit (3/8 in. outside diameter, 3/8 in. stainless steel (SUS) 304), an outer methanol SR unit (1 in. outer diameter, SUS 304), and an outermost evaporation/heat-exchanger unit. The inner combustion-reaction unit supplies a major portion of the heat to the reforming unit by the total oxidation of methanol in air. Its flue gas subsequently exchanges the remaining heat with the incoming reforming-feed stream. The reforming-feed stream consists of methanol and water – both of which are evaporated by the heat exchange with the flue gas – is fed to the reforming unit and therein undergoes an endothermic SR reaction.

The reformatted gas stream is cooled while passing through a separator located in the fuel tank, and the unreacted methanol and water are condensed back to their liquid forms. The reformatted gas stream (reformate hereinafter) is composed of 74% H_2, 24% CO_2, and about 1% CO. A stainless-steel thermos unit insulates the reformer that has a total volume of 260 cm^3. The percentage of CO is further reduced by PROX of CO with air.

2.2. Stack

Single-cell module: Independent of the investigated flow field, each fuel cell was constructed with an Umicore® membrane–electrode assembly (Series R300E, catalyst loading of anode and cathode: 0.8 mg Pt cm^{-2}; PtRu anode + Pt cathode) sandwiched between TORAY® carbon paper (TGPH-090, Japan).

The set-up was placed between the flow-field plates, which were made of SGL SIGRACET® material (R8710). Stainless-steel plates were placed on either side to provide external electric circuit connections and to compress the stack. The application of a high clamping pressure (120 N cm^{-2}) of the cell reduced the contact resistance and affected the fuel cell performance positively. The total active area of the single-cell module was about 90 cm^2.