INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 33 (2008) 2330–2336

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Development of a 700 W anode-supported micro-tubular SOFC stack for APU applications

Seung-Bok Lee[a], *Tak-Hyoung Lim*[a], *Rak-Hyun Song*[a], *Dong-Ryul Shin*[a,*], *Sang-Keun Dong*[b]

[a]*Advanced Fuel Cell Research Center, Korea Institute of Energy Research, 71-2, Jang-dong, Yuseong-gu, Daejeon, Republic of Korea*

[b]*Industrial Combustion Technology Research Center, Korea Institute of Energy Research, 71-2, Jang-dong, Yuseong-gu, Daejeon, Republic of Korea*

ARTICLE INFO

Article history:
Received 2 May 2007
Received in revised form
7 November 2007
Accepted 15 February 2008
Available online 8 April 2008

Keywords:
Micro-tubular SOFC
Anode-supported SOFC
SOFC stack
APU

ABSTRACT

A 700 W anode-supported micro-tubular solid-oxide fuel cell (SOFC) stack for use as an auxiliary power unit (APU) for an automobile is fabricated and characterized in this study. For this purpose, a single cell was initially designed via optimization of the current collecting method, the brazing method and the length of the tubular cell. Following this, a high-power single cell was fabricated that showed a cell performance of 0.54 W/cm^2 at 0.7 V and 800 °C using H_2 (fuel utilization = 45%) and air as fuel and oxidant gas, respectively. Additionally, a fuel manifold was designed by adopting a simulation method to supply fuel gas uniformly into a single unit cell. Finally, a 700 W anode-supported micro-tubular SOFC stack was constructed by stacking bundles of the single cells in a series of electrical connections using H_2 (fuel utilization = 49%) and air as fuel and oxidant gas, respectively. The SOFC stack showed a high power density of 0.38 W/cm^2; moreover, due to the good thermo-mechanical properties of the micro-tubular SOFC stack, the start-up time could be reduced by 2 h, which corresponds to 6°/min.

1. Introduction

A solid-oxide fuel cell (SOFC) is a type of fuel cell identified as an emerging technology for clean, reliable and flexible power production. The main advantages of SOFCs are both high conversion efficiency and fuel flexibility that allows a variety of fuels to be used [1–4]. There are two types of design for SOFCs: planar-type SOFCs and tubular-type SOFCs. Planar-type SOFC systems have superior characteristics to tubular-type SOFC in terms of their power density due to the more effective current collection by a planar interconnector. In contrast, tubular SOFC systems have superior characteristics to planar SOFCs in terms of their thermal and mechanical properties [5–7].

Fuel cell applications such as auxiliary power units (APUs) require their stacks to turn on and must reach their operating temperature as soon as possible. In general, planar SOFCs are considered fragile and unable to endure the rapid heating and cooling needed for these demanding applications [8–12]. In particular, the sealing layers need to be compatible with all the cell components; thus, most of the cell failures are imputable to a sealing problem. There are two main approaches for solving these problems. One consists in re-designing the single cells, to avoid or reduce phenomena that cause cell failure. Another is to employ new materials and manufacturing processes to provide the cell with the needed characteristics. One example of the first approach is the tubular design that has been developed specially for SOFC for avoiding the sealing and cracking problems. However, the tubular type cell configuration leads to a long current path, which generates high ohmic

*Corresponding author: Tel.: +82 42 860 3015; fax: +82 42 860 3309.
E-mail address: drshin@kier.re.kr (D.-R. Shin).

0360-3199/$ - see front matter © 2008 International Association for Hydrogen Energy. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijhydene.2008.02.034

resistance. Moreover, in the case of tubular type SOFC stack, it is difficult to uniformly supply fuel gas and air to each single cell.

Therefore, in order to solve the problem regarding the high ohmic resistance and non-uniform gas supply, we developed a new current-collecting method and we designed a gas supply manifold. Based upon these results, we developed a 700 W anode-supported micro-tubular SOFC stack for APU application.

2. Experimental

The extruded tubular anode support served as a fuel electrode. The other cell components were coated in thin layers on the anode. A 40 vol% of Ni—8YSZ (8 mol% Y_2O_3-stabilized ZrO_2) anode powder was prepared by mixing 8YSZ (TZ-8Y, Tosoh Co.) and nickel oxide powders (JT Bakers Co.). The anode powder and activated carbon as a pore former were weighed and mixed in ethanol by ball milling for 14 days and were then dried. Organic binder and 25 wt% of distilled water were added to the dried powder, and became homogenously dispersed to form a paste. The dispersed paste was extruded in the form of a micro-tube.

The extruded tubes were dried in a drying furnace at 120 °C for 12 h and the dried tubes were pre-sintered at 1100 °C. A YSZ electrolyte layer was coated onto the surface of the pre-sintered tube using a vacuum slurry dip-coating method to form a thin and dense layer, and this was co-fired at 1400 °C. The thickness of the electrolyte layer was approximately 5 μm. Cathode materials, LSM ($(La_{0.85}Sr_{0.15})_{0.9}MnO_3$) and LSCF ($La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$) were prepared by a solid-state reaction. The starting materials were weighed in the required proportions and mixed in ethanol by ball milling for 10 days. The mixed powder was calcined at 1000 °C for 5 h. The multi-layered cathode composed of the LSM/8YSZ composite layer, the LSM layer, and the LSCF layer were coated onto the co-fired electrolyte surface via a slurry dip process and the coated cathode layers were sintered at 1200 °C for 5 h.

3. Results and discussion

An anode-supported micro-tubular SOFC single cell for APU application was initially designed. Fig. 1 shows a schematic diagram of the single-cell design. It contains a fuel–gas supply tube within a cell. For this cell design, the following effects are expected:

(i) Enhancement of the gas utilization efficiency by reducing the gas flow channel within the anode tube.
(ii) Pre-heating effect of the fuel gas using a high-temperature gas supply tube.
(iii) Metallic gas supply tube that serves as an anode current collector, which leads to the reduction of ohmic resistance of the anode current collector.
(iv) Reduction of the stack volume via the reduced number of manifolds for the fuel gas.

For the anode-supported tubular-type SOFC, the effective collecting of the electrical current from anode part of the single cell presented a challenge, as the electrical current was to be collected from the inside of the tubular cell [13,14]. Therefore, generally very high polarizations are established across the anode tube wall and anode current collector, which leads to a significant decrease in the power density of a single cell. Thus, in this study, in order to reduce the ohmic resistance caused by anode current collectors, a gas supply tube and Ni wires were used as the anode current collectors.

Simultaneously, to reduce the contact resistance between the anode wall and the anode current collector, Ni felt and Ni paste were used at the interface between the anode tube wall and the Ni wire, respectively, as well as at the interface between the Ni wire and the gas supply tube, respectively. First, Ni wires were spot-welded to the Ni felt at identical intervals, the attached Ni component was then inserted into the tube, and the gas supply tube was again tightly inserted into the attached component. Accordingly, tight contact among the anode wall surface, the Ni felt, the Ni wire and the gas supply tube was assured. A schematic diagram of a cross-sectional view of the single cell is illustrated in Fig. 2. The dimensions of the developed single cell were 10 mm in diameter and 200 mm in length, and the dimensions of the effective area were 10 mm in diameter and 160 mm in length.

Fig. 3 shows the performances of a conventional micro-tubular SOFC single cell without fuel supply tube and the newly developed micro-tubular SOFC single cell which contains the gas supply tube and the Ni felt. As compared with the performance of a conventional SOFC single cell, the $I-V$ curves reveal that the performance of the newly developed single cell dramatically increased from 0.24 to 0.54 W/cm^2 at 0.7 V and 800 °C using H_2 (fuel utilization = 45%) and air as fuel and oxidant gas, respectively. This is likely due to the use of the

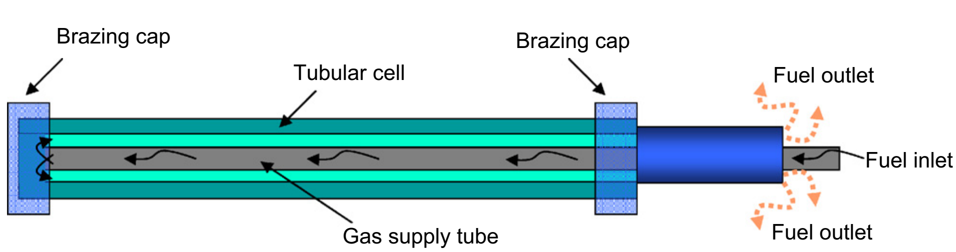

Fig. 1 – Schematic diagram of a SOFC single cell.