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An experimental investigation of pressurized planar solid oxide fuel cells using two different flow distributors

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HIGHLIGHTS

- A high-pressure dual-chamber facility is established for pressurized SOFC studies.
- Electrochemical impedance spectra of PSOFC using single-cell stacks are measured.
- These EIS data explain why and how the cell performance is increased with pressure.
- This study is useful to the development of PSOFC integrating with micro gas turbines.

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ABSTRACT

A high-pressure high-temperature dual-chamber facility is established for electrochemical impedance measurements of pressurized solid oxide fuel cells (PSOFC) to explain why and how the cell performance is increased with increasing pressure (p). By comparing two sets of nearly identical single-cell stacks except using different flow distributors with different degrees of flow uniformity at 850 °C over a range of p varying from 0.1 MPa to 0.5 MPa, we found that the better flow uniformity in flow distributors is, the better the cell performance is, and such performance enhancement is increased with increasing p. This finding is explained by impedance spectra and their associated equivalent circuit models, showing the coupling impact of flow uniformity and pressure elevation to the decrease of ohmic and polarization resistances. These results should be useful to the development of PSOFC integrating with micro gas turbines for future stationary power generation.

1. Introduction

Keeping pace with a rapid increase in population, prosperity, and the desire for improving the quality of life, the demand for electricity as the major form of applicable energy in our modern society has been drastically increased over the past. In the beginning of twenty century, only 1% of all fossil primary energy was converted to electricity, but in recent years this has been increased worldwide to about 40% [1,2]. Further, such increasing trend is expected to rise in relation to the advances of the gross national product in the future. The excessive consumption of energy and natural resources, deforestation, land use and land cover changes, and air, land and water pollution caused by human activities had unfortunately already put tremendous impact on the Earth. Nowadays, we are facing many serious environmental and energy shortage problems. Delay of action will jeopardize the ability of future generations to meet their needs. Hence, highly efficient power generation systems with very low emissions are urgently needed in our modern society. Among a few potential candidates, the hybrid system including a pressurized solid oxide fuel cell (PSOFC) integrating with a gas turbine or micro gas turbine (MGT) has the highest efficiency [3–12]. This motivates the present study to measure the detail electrochemical characteristics of PSOFC which is the essential component of the hybrid system.

The hybrid PSOFC–MGT power system may be expected to reach efficiencies approaching up to 70% [3]. Such a highly efficient synergetic technology not only has great potential for reducing the fuel consumption and the capital cost per unit power output [3–11], but also it has a very wide range of applications from some 10 kW to multi MW [12]. Thus, the PSOFC–MGT system is important to the advance of the fuel cell technology as well as for the expansion of the gas turbine industry. There are a few demo

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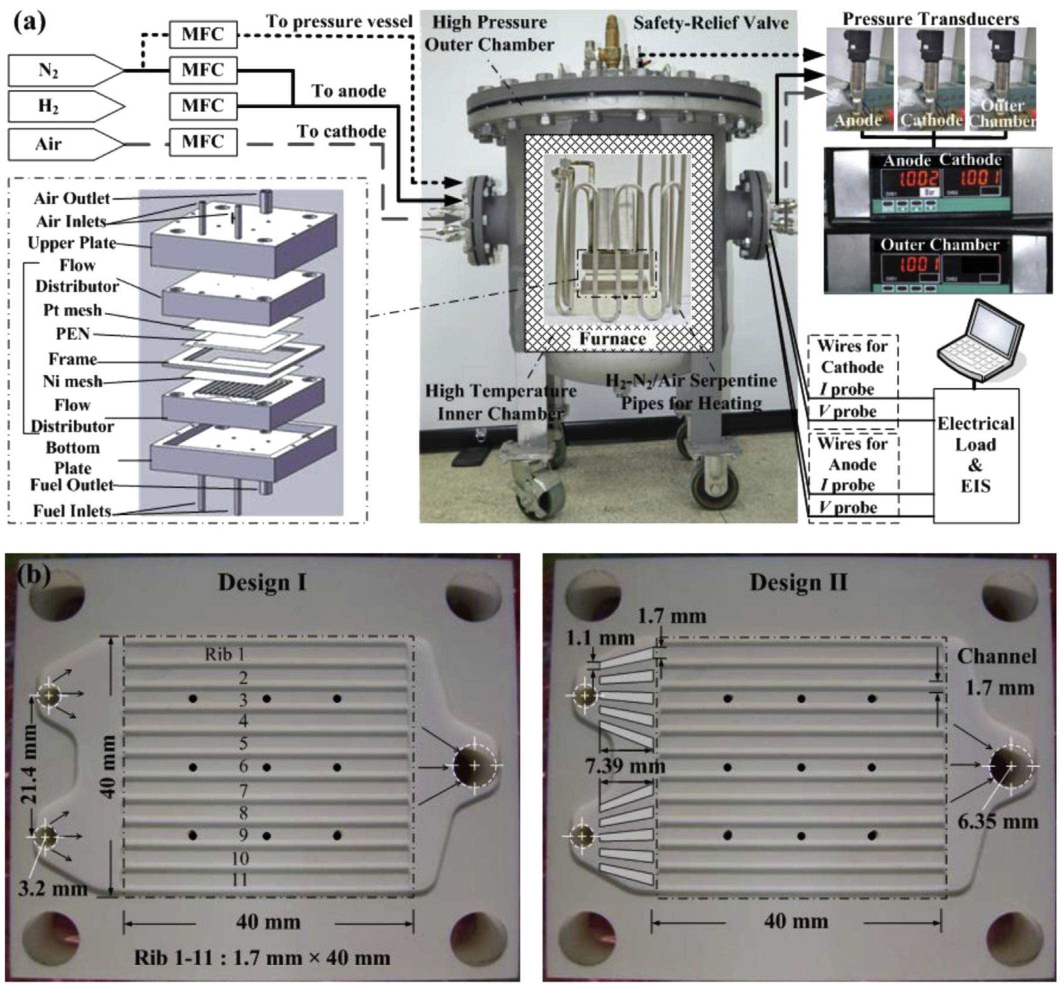

Fig. 1. (a) A high-pressure double-chamber planar solid oxide fuel cell testing platform. (b) Two flow distributors, designs I and II.

examples available for the hybrid PSOFC–MGT power system deserving to mention. For instances, Siemens had showed the feasibility with its 220 kW PSOFC–MGT hybrid system (PH220) [6], the Korea Institute of Energy Research tested a 30 kW (5 kW PSOFC integrated with 25 kW MGT) hybrid system [7], Mitsubishi Heavy Industries manufactured a 200-kW class hybrid PSOFC–MGT combined-cycle power plant and conducted a performance test in 2007 [8], and the German Aerospace Center (DLR) has started a project aiming to demonstrate a 50 kW hybrid PSOFC–MGT power system [12]. Though these demo examples are successful in some measure, many technical challenges in designing the hybrid power system and its control still remain to be solved before the safe and stable operation of PSOFC–MGT power generation system among different components can be assured to make the industrial application feasible. One of the most important technical challenges is the knowledge of the electrochemical characteristics of PSOFC. So far in the available literature, there are very few experimental data of electrochemical impedance spectra (EIS) for the PSOFC stack [12]. Hence, the objective of this study is to establish a high-pressure double-chamber testing platform for measurements of the PSOFC using a single-cell stack setup (a full cell with interconnectors) at elevated pressure (p) up to 0.6 MPa and thus the wanted EIS data can be measured for the first time.

The "single-cell stack" term has already been used by several research groups [e.g., [13–17]], which not only includes a "single cell" consisting of a positive electrode-electrolyte-negative electrode (PEN) and current collectors but also has flow distributors (interconnectors) in both anode and cathode. Previous studies under atmospheric pressure condition [15,16] applied various designs of commonly-used rib-channel flow distributors having different degrees of flow uniformity to measure the impact of flow uniformity in interconnectors on power generating characteristics of single-cell stacks. It was found that by improving flow uniformity in interconnectors can result in more than 10% increase of the cell power density without pressurization [15,16]. Such finding was further explained by the corresponding EIS measurements [17], in which the EIS data clearly showed that both ohmic and polarization resistances are smaller for the case of better flow uniformity in interconnectors. In the present study, we apply the same single-cell stacks as that previously used in Refs. [15–17] but with new modifications for conducting high-pressure SOFC experiments as to be discussed in detail. In short, we aim to measure the impact of flow uniformity in interconnectors on the cell performance and electrochemical characteristics of single-cell stacks under elevated pressure conditions, so that the following questions may be addressed. How exactly would the power generating characteristics of anode-supported single-cell stacks vary with a change of pressurization? What is the effect of flow uniformity in interconnectors on the cell performance and electrochemical impedance spectra of single-cell stacks at elevated pressures? Can the measured EIS data of single-cell stacks under both unloaded and loaded conditions over a range of pressure be used to explain quantitatively the coupling influence of pressurization and flow uniformity in interconnectors on the cell performance of PSOFC? It should be noted