R&D on All Ceramics SOFC with High Power Density under 1,000℃ Operation

Background

Electric power generation using the solid oxide Fuel cells (SOFC) is believed to be a good candidate for a highly efficient electric power generation system with effectively utilizing high temperature waste heat, and to be its excellent environmental characteristics additionally. In particular the 1,000℃ operating type SOFC are expected to achieve a simplified system based on the direct reforming of gaseous fuel.

However, in the view of the hard operating conditions, it is necessary for high temperature SOFC to make up the system entirely with ceramics along with the optimization of the cell and stack structures, materials and manufacturing technologies while ensuring a low cost and achieving high power density and improved durability. The CRIEPI has proposed an anode supported type structure to allow the 1,000℃ operation, that is all ceramics SOFC, and then has confirmed the excellent performance of the prototype unit cell [*1] using the basic material and membrane forming technique (Table 1). To validate the practical use of such unit cells, it is still necessary to advance the electricity generation property and availability of the stack using multiple unit cells.

Objectives

To clarify the property and availability for the anode supported SOFC, two prototype all ceramic 3cell stack were prepared, and then were overhauled and analyzed after the generation tests, in which the unit cells were developed by CRIEPI. The target of the performance was over 0.5 W/cm^2 in power density of the several unit cells, which is one indicator for cost reduction.

Principal Results

1. Stack structure (Table 1)

The all ceramic stack is configured as described below, incorporating the unit cells and connection parts.

① Concerning on the unit cells, a dense electrolyte layer and an interconnector membrane, specially developed by the CRIEPI, are formed on a porous anode substrate (5.0 cm × 5.0 cm) with gas channels which is made of along-life anode material, followed by the introduction of a cathode (area of approximately 12.0 cm^2) layer above the electrolyte layer to prepare the unit cell.

② The connection parts have roles in electrical connections between the unit cells and air channels for the cathode of the several cells. This parts were prepared by using cathode material and were placed between the unit cells. The end part, where was settled on the end of the stack, was an anode substrate coverd over the entire surface by the interconnector membrane (Fig.1).

2. Electric Generation Properties at 1,000℃ (Table 2, Fig.2)

The stacks were heated up to 1,000℃ and were fed with hydrogen gas and air to evaluate the electric generation properties .

① The fact that the open circuit voltage of the unit cell is practically identical to the theoretical value means that there is hardly any cross leakage [*2] of the gas fed to the unit cell, indicating a satisfactory gas sealing performance.

② At a unit cell voltage of 0.7 V, a power density exceeding the development target of 0.5 W/cm^2 is obtained. The level of property is maintained even after continuous generating operation for 150 hours.

3. Overhaul-Analysis of the Stack after Test

Any removement of the electrolyte layer and interconnector membranes formed on the anode substrate and/or any damage to the unit cell are not observed hardly. The absence of decomposition of any part or reaction product between the any parts shows the availability of the tested stack.

Results of the stack tests, the anode supported type SOFC using the unique technology developed by the CRIEPI shows a high electric power generation properties at 1,000℃ and availability vindicated by the absence of any damage or material degradation which is a fatal problem for the unit cell to gain practicality, suggesting a positive prospect for its potential use in the future.

Future Developments

Further research will be conducted to remove the connection part from stack, to enlarge the surface area of the unit cell and to improve the gas manifold and output collector structure, all of which are essential for cost reduction, while establishment for the stacking technology is advanced to apply the SOFC for the practical use.

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Reference

Hibiki Itoh, Kenji Yasumoto, Tohru Yamamoto and Yasuo Takada, 2004, “Research and Development on Anode-Supported Type SOFC Stack - Preparation and Investigation of the Electricity Generation Characteristics for 3 Cell Stacks with High Power Density in All Ceramics Under 1,000℃ Operation”, CRIEPI Report W03039 (in Japanese)

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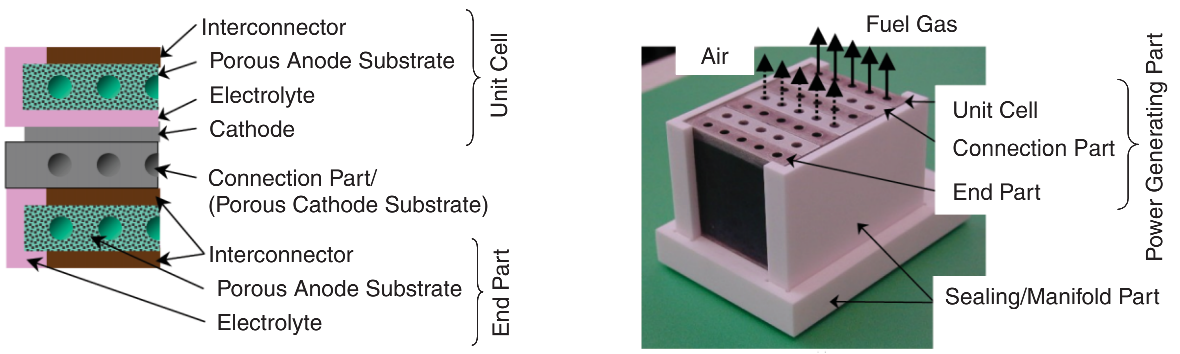
*1 : Single cell which is the unit of a stack: a stack is completed when multiple unit cells are connected.
*2 : Gas leakage at dense membrane (electrolyte and interconnector) formed on the unit cell.
When cross leakage occurs, the open circuit voltage fails to show the theoretical value.

Table 1 Parts of Prototype Anode Supported Type SOFC Stack

Part		Com poison/Material	
Unit Cell	Anode (Porous Substrate)	Ni-YSZ cermet (developed by the CRIEPI)	5 cm square sintered anode substrate with gas channels
Unit Cell	Electrolyte (Dense layer)	YSZ powder (market product)	Formed on the anode substrate using the slurry coating method
Unit Cell	Cathode (Porous Membrane)	(La, Sr) MnO_3 (developed by the CRIEPI)*	Formed on the electrolyte membrane using the slurring coating method
Unit Cell	Interconnector (Dense Membrane)	Lanthanumchromite + Intermediate Layer (developed by the CRIEPI)	Intermediate membrane and lanthanumchromite formed on the anode substrate in that order using the slurry coating method
Connection Part (Porous Substrate)		(La, Sr) MnO_3 (developed by the CRIEPI)	5 cm square sintered anode with gas channels
End Part (Porous Substrate)		Ni-YSZ cermet (developed by the CRIEPI) + Interconnector membrane (developed by the CRIEPI)	Interconnector membrane formed on the 5 cm square YSZ supported type sintered material with gas channels
Sealing and Manifold Part		Glass ceramics	Gas channels added to the market product

Note: Although a cathode material with a better performance in terms of the voltage loss and stability under a high current density has been developed, the previous cathode without such improvements is used for the present research.



(a) Conceptual Structure of Prototype Stack (b) External Appearance of Prototype Stack

Fig.1 Structure and External Appearance of Prototype Stack

The gaseous fuel and air are supplied as parallel flows from the lower end of the stack to the upper end, and the generated electricity is collected by pressing metal felt on the interconnector and end part of the unit cell placed at the end.

Table 2 Results of Electric Generation Tests

	No.1 Stack	No.2 Stack
Fuel Gas	H_2 (35℃ humidified) + N_2 (0.5 L/min) =2.0 L/min	H_2 (20℃ humidified) = 0.75 L/min
Oxidizing Gas	Air= 4.0 L/min	Air = 1.5 L/min
Open Circuit Voltage	3.05 V	3.33 V
Maximum Output (Power Density)	23.5 W (1.3 Vx 17.5 A) (0.64 W/cm²)	18.0 W (1.9 Vx 9.5 A) (0.52 W/cm²)
Output at 0.7 V (Power Density)	18.4 W (2.2 V x 8.7 A) (0.52 W/cm²)	17.5 W (2.1 V x 8.3 A) (0.50 W/cm²)

Note: The power densities in this table are the converted value to the unit cell (output/3 cells/surface area of cathode).

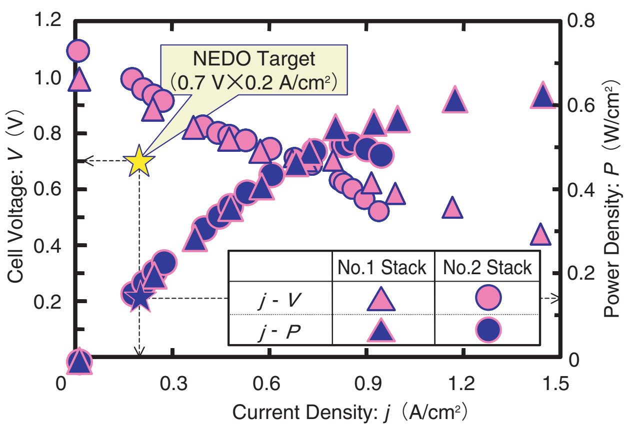


Fig.2 Results of Electric Generation Tests

The power generation test using two prototype stacks was conducted for the present research to evaluate the availability of the unit cell and the stacks. The differences in the electric generation properties between the No.1 stack and No.2 one are caused by the different flow rates of the supplied gases.