DISCHARGE CHARACTERISTICS OF PLANAR SOFC

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ABSTRACT

Performances of planar configuration solid oxide fuel cells were investigated. The single cells with 50×50mm self supporting electrolyte were operated using hydrogen gas and air. 10 cell samples were tested. The contact resistance dominated the cell resistance rather than the material resistance and it was mainly ascribed to the contact between cathode and cathode side separator. Gas utilization test indicated that the electrode polarization was mainly due to cathode. Cells were operated under conditions of high hydrogen utilization. Nominal efficiency of 40% LHV and output power density of 0.19W/cm² were obtained and any obvious degradation was not observed for 1000 hours.

INTRODUCTION

TONEN Corporation started research on SOFC in 1986. The main objectives of this program are to apply the planar SOFC to an energy conversion device for a cogeneration system and for transportation. TONEN has proposed a planar configuration: sintered electrolytes and interconnector are stacked one after another, and the stacked cells assemble easily. The validity of this design has been confirmed by 1300W output, 30 cells stack. In parallel, the technical effort has improved the properties of electrolyte and interconnecting materials. Alumina added fully stabilized zirconia possesses almost the same conductivity as fully stabilized zirconia but higher mechanical strength. The substitution of Cr site by a transition metal in LaCrO₃ has dramatically improved its air sinterability with high electrical conductivity, and it provides gas-impermeable interconnector. These fundamental investigations have allowed progress with SOFC. This paper presents recent performance characteristics of single cells.

EXPERIMENTAL

Single cells had 50X50mm self supporting electrolyte and cross flow structure as shown in Fig.1. Eight mol% Y₂O₃ doped zirconia (8YSZ) was used for the electrolyte; its thickness was about 0.2mm. La₁₋ₓSrₓMnO₃ and Ni/ZrO₂ cermet were used as the cathode and the anode, respectively. These were painted on the 8YSZ electrolyte with an active area of 16cm². An improved LaCrO₃ was used as cathode side separator and an improved LaCrO₃ or Ni metal was used as anode side separator. The improved
LaCrO$_3$ was La$_{0.8}$Sr$_{0.2}$CrO$_3$ and a density higher than 95%. Gas tightness was maintained by glass sealing between electrolytes and separators, and between a manifold and four corners. The manifold was made of alumina.

The cells assembly is heated and held at 1000°C. A thermocouple was placed at the exit of the manifold. Air and hydrogen were supplied to each electrode as feed gases. Two platinum probes were connected with each separator and a platinum wire(c') was embedded into the cathode. Cell discharge properties were measured at a constant current using 4 probes of separators. A current interruption method was used for the resistance measurement: the cell current was switched from 3A to off and the voltage shift within 5µsec was observed. Resistances calculated from voltage shifts between separators and between cathode side separator and c' were assigned as the cell resistance and the cathode contact resistance, respectively.

The nominal efficiency $\eta$(LHV) was defined as

$$\eta = \frac{\text{Cell voltage} \times u_f}{1.25}$$

$u_f$ denotes hydrogen utilization and the formation enthalpy at 298.15K is 1.25eV.

RESULTS AND DISCUSSION

Table I shows the cell resistances. The cell resistances ranged from 13 to 36mΩ and depended little on whether the material of anode separator was Ni metal or improved LaCrO$_3$. The equivalent cell circuit is shown in Fig.2. Cell resistance consists of a electrolyte resistance $R_2$, a material resistance of two separators $R_3$ and a contact resistance $R_1$ between cathode and separator. The electrical conductivities of 8YSZ, the improved LaCrO$_3$ in air and Ni metal are 0.15, 50 and $>10^2\Omega \text{-cm}^{-1}$, respectively, at 1000°C; hence the total material resistance $R_2+R_3$ is estimated to be 10 mΩ. Values of contact resistance $R_1$ between cathode(c') and cathode separator were measured in No.7 and No.9 cells and values of 16 and 18mΩ were obtained as shown in Table II. These data indicate that half-cell resistance can be ascribed to the contact resistance $R_1$.

Table II also shows the electrodes polarization. In order to investigate the anode polarization, fuel utilization was switched from $u_{f1}$ to $u_{f2}$ though the discharge current was held at 5A and the voltage difference was measured. The values of 160 and 120mV were obtained in No.7 and No.9 cells. The values include Nernst losses which are estimated to be 161 and 122mV, provided that concentrations of hydrogen gas and steam are uniform in the cell and the Nernst loss is approximately equal to:

$$\frac{RT}{2F} \ln \left( \frac{1-u_{f1}}{u_{f1}} \times \frac{u_{f2}}{1-u_{f2}} \right)$$

This consistency indicates that anodic polarization is small. A cathodic polarization was also obtained by the measurement of the voltage differences between oxygen gas and air at 5A constant current. The measured values were 54 and 99mV in each cell and the calculated value is 44mV. Therefore, 10 and 55mV is ascribed to activation or diffusion polarization of the cathode.

Fig.3 shows the relation of the output power density to the nominal efficiency. The output power density of 0.19W/cm$^2$ was observed at a nominal efficiency $\eta=40%$(LHV). The higher power density value is expected at $\eta=40%$ if the fuel feed is a hydrocarbon such as methane, because the maximum theoretical efficiency of hydrocarbon is higher than that of hydrogen.
Fig. 4 shows continuous discharge test of No. 7 cell. The cell was initially operated using hydrogen and oxygen gas. Cathode feed gas was changed to air as the output increased. From about 130 hours, the hydrogen and air utilizations were kept at 80% and 17.5%. The power density of cell remained nearly constant until 1000 hours.

CONCLUSIONS

Performance of planar configuration solid oxide fuel cell was investigated. The single cells with 50×50mm self supporting electrolyte were operated using hydrogen gas and air. Cell Resistances of 10 cell samples were measured using a current interruption method and the value ranged from 13 to 31 mΩ. Estimated value of material resistance was about 10 mΩ and contact resistances of two cell were 16 and 18 mΩ. These indicate that contact resistance between cathode and cathode side separator dominates cell performance.

Cells were operated under conditions of high hydrogen utilization. Nominal efficiency of 40% LHV and output power density of 0.19 W/cm² were obtained and any obvious degradation was not observed for 1000 hours.

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Table I  Cell resistances of 10 single planar SOFC

| Anode Separator | Ni  | ILC | ILC | ILC | Ni  | ILC | ILC | Ni  | ILC | ILC |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Cell Resistance | 13  | 30  | 17  | 29  | 18  | 22  | 23  | 31  | 36  | 34  |

ILC: Improved LaCrO₃
Table II  Contact resistances and electrode polarizations

| Cell number | 7   | 9   |
|-------------|-----|-----|
| Contact resistance [m Ω] between cathode(c') and cathode separator | 16  | 18  |
| Voltage difference between uf1 and uf2 [mV] | ~160, uf1=17.5% uf2=80% | ~120, uf1=20% uf2=70% |
| Voltage difference between oxygen and air [mV] | 54  | 99  |
Fig. 3 Relation of power density to nominal efficiency:

Fig. 4 Continuous discharge test
- Region A: hydrogen 200cc/min, oxygen 100cc/min
- Region B: hydrogen utilization 17.5%, Air 700cc/min
- Region C: hydrogen utilization 80%, Air 700cc/min