THE PERFORMANCE AND RELIABILITY OF 20cm SQUARE PLANAR SOFC

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ABSTRACT

TONEN CORPORATION has developed a planar SOFC utilizing hydrocarbon fuel. This paper describes the effect of propane reforming condition such as steam to carbon ratio (S/C) on the cell performance. 5cm square single cell was pretested by propane reformed gas that was obtained under the condition of 2~4 S/C. Carbon formation was not found in the reformer or the cell, and an electric efficiency higher than 40% (LHV) and power density of 0.2 W/cm² were obtained in the range of 2~3.6 S/C. Based on these results, 20cm square 3 cells stack was tested under the similar condition. The effect of cell size on the cell resistance was not observed. We obtained the electric efficiency of 40% and the power density of 0.2 W/cm² from propane reformed gas of S/C = 2, and the performance was stable for about 1000 hours.

INTRODUCTION

TONEN CORPORATION started the research on SOFC in 1986. After demonstrating 1.3 kW in 1991, we studied to raise electric efficiency and reliability. As a result of improving the cell components and assembling methods, higher than 40% electric efficiency and a power density of about 0.2 W/cm² in the 5cm square single cell tests with hydrogen fuel were obtained, and 7500 hours continuous discharge test was carried out.

In parallel, we started to research on the planar SOFC utilizing hydrocarbon fuel. From the propane thermal cracking test, it was found that carbon deposition occurs above 780 °C and the external reforming was better than internal reforming for propane fuel.

EXPERIMENTAL

Our SOFC is composed of square self-supporting electrolyte with electrode
and separator. The electrolyte is made of 8 mol% Y₂O₃ doped ZrO₂ (8YSZ), with a thickness of approximately 0.2mm. Anode and cathode electrodes were LaₓSrₓMnO₃ and Ni/ZrO₂, respectively. The separator is a improved LaCrO₃ in which La and Cr site are substituted by Sr and Co, respectively. Gas tightness was maintained by glass sealing between electrolytes and separators, and between manifold and four corners.

The cells assembly was heated and held at 1000°C. The feed gases were reformed or preheated by electric furnaces. The catalyst for steam reforming of propane was Ru/ZrO₂. Two platinum probes were connected to each side separator. The discharge properties such as I-V characteristics, electric efficiency and power density were measured at a constant feed gas rate by these probes. A current interruption method was used for the resistance R measurements of single cells less than 15cm square. The resistance R of 20cm square cell was defined as

\[ R = \left( \frac{V_{\text{Nernst}} - V_{\text{cell}}}{I} \right) \times S - 100 \]

\( V_{\text{cell}} \) and \( V_{\text{Nernst}} \) denote a measured cell voltage and the calculated voltage from Nernst equation, respectively. S means effective electrode area. The polarization resistance is assumed to be 100 mΩcm². In this paper \( V_{\text{Nernst}} \) was simply expressed without considering shift reaction as

\[ V_{\text{Nernst}} = E_0 + \frac{RT}{nF} \ln \left( \frac{P_{\text{H}_2} \times (1 - \frac{U_f}{100}) \times P_{\text{O}_2}}{P_{\text{H}_2} + P_{\text{H}_2} \times \frac{U_f}{100}} \right) \]

\( U_f(\%) \) denotes fuel utilization ratio. The electric efficiencies \( \eta \) (LHV) of hydrogen and propane were also defined as

\[ \eta(H_2) = \frac{V_{\text{cell}} \times U_f}{1.25} \]

\[ \eta(C_3H_8) = \frac{V_{\text{cell}} \times U_f}{1.06} \]

RESULTS AND DISCUSSION

Effect of S/C on 5cm square single cell performance

Fig. 1 shows the relation between the carbon deposition and S/C ratio in propane steam reforming from thermodynamic equilibrium calculations. The carbon
deposition occurs at less than S/C=1.6. Such a reforming condition cannot be used for the SOFC system.

Fig. 2 shows the I-V characteristics of 5cm square single cells with non-humidified hydrogen fuel and propane fuel. The I-V curve of the propane fuel lies below that of the non-humidified hydrogen fuel. This is due to the difference of the steam concentration in fuel. Table 1 shows the reformed gas composition at 1000 °C from the thermodynamic equilibrium calculations.

The relation between the S/C and cell performances is shown in Fig. 3. On each S/C condition of 2~4 S/C, the cell resistance didn't change. Higher electric efficiency than 40% and power density of 0.2 W/cm² were shown in the range of 2~3.6 S/C. The electric efficiency and the power density tended to decrease with the S/C. Lower S/C is desirable for cell performance.

Performance of 20cm square 3 cells stack

Based on 5cm single cell tests, 20cm square 3 cells stack tests were carried out. Fig. 4 shows I-V characteristics of three 20cm square stacks. #1, #2, and #3 stack were operated under the feed gas conditions of H_{2}/H_{2}O = 3/1, S/C = 2, S/C = 2.3. Reformed gas of S/C = 2 contained hydrogen and steam, which ratio was about H_{2}/H_{2}O = 3/1 as shown in Table 1. Therefore I-V characteristic of #1 fits to that of #2. A large leakage does not seem to occur, because the value of their stacks' OCV agreed with theoretical value.

The relation between power density and electric efficiency of #1 and #3 stacks is shown in Fig. 5. In the hydrogen fuel, the electric efficiency and the power density were over 40% and 0.2W/cm² respectively at U_f = 74.6% and I_q = 0.3 A/cm². In the propane fuel, the same performances could be obtained at U_f =60%.

The continuous discharge test with propane fuel of #3 stack is shown in Fig. 6. It was operated at U_f = 60% and 0.28 A/cm². It was confirmed that the output power of the 20cm square 3 cells stack had been stable for 1000 hours.

Dependence of cell size on cell resistance

From the results of these 20cm square cells tests and other size cells tests, the relation between cell size and cell resistance is shown in Fig. 7. Our planar SOFC's resistance greater than 3cm square is nearly constant. So far as cell resistance is concerned, it is possible to realize 30cm square cell.

The difference between the cell resistance and the electrolyte material resistance is about 150 mΩcm² in Fig. 7, this is supposed to be an interfacial resistance.
resistance. Therefore 3cm square cell resistance was lower than other size resistance, because smaller electrode area is easier to get better contact.

CONCLUSIONS

The effect of propane reforming condition on the cell performances were investigated in 5cm square single cell and carried out 20cm square 3 cells stack tests. In conclusion,
1) Higher than 40% electric efficiency and a power density of about 0.2 W/cm$^2$ were obtained in the range of 2–3.6 S/C in 5cm square single cell.
2) 40% electric efficiency and 0.2 W/cm$^2$ power density were obtained at S/C=2 in 20cm square 3 cells stack.
3) 20cm square 3 cells stack performance was stable for about 1000 hours,
4) Our planar SOFC resistance was independent of cell size.

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Table 1 Effect of S/C on reformed gas composition at 1000 °C

| S/C | 2.0  | 3.0  | 4.0  |
|-----|------|------|------|
| H₂  | 57.7 | 49.1 | 42.7 |
| H₂O | 19.2 | 32.2 | 41.5 |
| CO  | 19.2 | 13.4 | 9.9  |
| CO₂ | 3.9  | 5.3  | 5.9  |

Fig. 1 Relation between S/C and carbon deposition at 600 °C
Fig. 2  I-V characteristics of 5cm square single cell

Fig. 3  Effect of S/C on cell performances
Fig. 4  I-V characteristics of 20cm square 3 cells stack

Fig. 5  Relation between electric efficiency and power density
Fig. 6  Continuous discharge test of 20cm square 3 cells stack

Fig. 7  Dependence of cell size on cell resistance