Performance Evaluation of Solid Oxide Fuel Cells Directly Using Biogas Fuel at High Fuel Utilizations

Jingyi Tan [a], Aki Miyawaki [b], Shinya Teranishi [b], Masahiro Nagao [a], Takashi Hibino [a,c]
[a] Graduate School of Environmental Studies, Nagoya University,
[b] SOKEN, INC., Nisshin, Aichi,
[c] Department of Research, Nagoya Industrial Science Research Institute,
Email: tan.jingyi.i5@s.mail.nagoya-u.ac.jp

Introduction

Biogas, typically containing 50–70% CH_4 and 25–55% CO_2, is a promising renewable fuel. Recent studies have explored direct utilization of biogas in SOFCs because of their high efficiency and fuel flexibility. The performance of SOFCs is strongly influenced by the CH_4:CO_2 ratio, flow rate, and many research groups have tried to increase the fuel utilization by adding various catalysts to the anode, but the resulting power densities are significantly reduced[1-2]. In this study, a large porous Ni–YSZ anode was designed to enhance gas diffusion and release of product gases, thereby enabling stable SOFC operation under high fuel utilization conditions. The roles of CO_2 and fuel humidification were systematically investigated to clarify their influence on power generation and degradation mechanisms.

Experimental Procedures

Two SOFCs with Ni–YSZ anodes of 1.03 µm (normal) and 7.05 µm (large) pore sizes were fabricated by tape casting. The cell structure consisted of a Ni–YSZ anode, YSZ electrolyte, GDC buffer, and LSCF cathode. The model biogas fuel was a CH_4–CO_2 mixture (1:1) supplied at total flow rates between 5 and 40 mL min^{-1}, unhumidified or humidified at 800 °C, and air was supplied to the cathode at 20 mL min^{-1}. Electrochemical performance was evaluated by I–V curves, electrochemical impedance spectroscopy, and long-term discharge at constant voltages. The outlet gases were analyzed by gas chromatography to determine fuel utilization and carbon balance.

Results and Discussion

The large-pore anode showed stable performance at low fuel flow rates compared with the normally porous anode. Peak power densities of 1.15W cm^{-2} was achieved at 5 mL min^{-1} with 66.7% fuel utilization. These values exceed previously reported performances under comparable conditions. XPS analysis after discharge further confirmed that humidification suppressed carbon deposition and improved the carbon balance (up to 66%), but also accelerated Ni oxidation and cell degradation. In contrast, unhumidified fuel suffered severe carbon deposition.

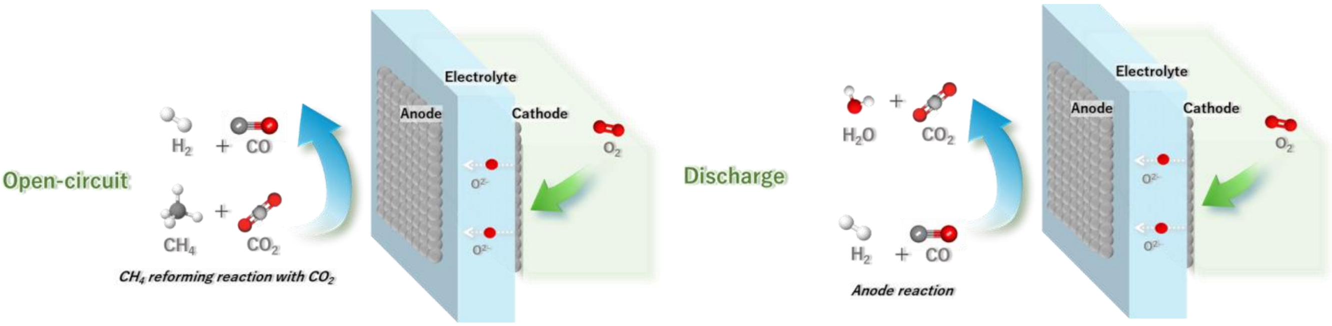

Figure 1 Graphical schematic of solid oxide fuel cell reaction

References

[1] Y. Yao, T. Chen, Z. Zhou, Z. Huang, P. Cai, L. Xu, S. Wang, Investigation of $La_{0.6}Sr_{0.4}Co_{1-x}Ni_xO_{3-\delta}$ (x=0, 0.2, 0.4, 0.6, 0.8) catalysts on solid oxide fuel cells anode for biogas dry reforming, Int. J. Hydrogen Energy 2022, 47, 28645–28654.

[2] S. Vecino-Mantilla, M. Lo Faro, Exsolved perovskites for reliable SOFCs fed with dry biogas, Int. J. Hydrogen Energy 2024, 95, 1151–1157.