High Temperature Steam Electrolysis Cells Using LaCoO₃-Based Anode and Ceria-Based Cathode

N. Osada,¹ H. Uchida,¹ M. Watanabe,² N. Suzuki,³ K. Matsunaga,³ M. Yoshino³

¹ Interdisciplinary Graduate School of Medicine and Engineering, ² Clean Energy Research Center, University of Yamanashi, Kofu, 400-8511 Japan ³Toshiba Corporation, Yokohama, 230-0045 Japan

Solid oxide electrolysis cells (SOECs) are expected, in principle, to provide the highest efficiency of electrolytic hydrogen production. An advantage of the SOECs is the reduction of applied voltage due to favorable thermodynamic and kinetic conditions. When the SOECs are operated reversely, they can work as the solid oxide fuel cells (SOFCs) to generate electricity with a high efficiency by consuming natural gas, coal gas, or stored hydrogen. Thus, such a cell is regarded as a reciprocal direct energy converter between hydrogen and electricity. The operating temperature of SOEC is, so far, restricted to temperatures of about 1000°C because of insufficient performance of the state-of-the-art electrolyte and electrodes at low temperatures. Lowering the operating temperature is, however, a good option to overcome a limited choice of the component materials resistant to mechanical degradation caused by thermal heat shock or to physical and chemical degradation due to material oxidation/reduction or to solid-phase reaction at an between different materials. interface The low temperature operation is also favorable to utilize various waste heat sources from steel-making or coal-gasification. It is essential to develop high performance electrodes for both SOECs and SOFCs operated at reduced temperatures. Recently, we developed a porous catalyzed-reaction layer for medium-temperature SOFCs. Mixed conducting oxide particles, samaria-doped ceria [(CeO₂)_{0.8}(SmO_{1.5})_{0.2}, SDC]¹⁾ for the anode and LaCoO₃-based material with SDC interlayer for the cathode,²⁾ were employed in combination with highly dispersed (nm sized) metal electrocatalysts on their surface. In this paper, we report the performances of these electrodes applied in SOECs to generate H₂ and O₂.

Onto an 8 mol% YSZ electrolyte disk, a porous SDC cathode with highly dispersed nanometer-sized Ni catalysts were prepared in the same manner as in our previous works of SOFC anodes.³⁾ A porous La_{0.6}Sr_{0.4}-CoO₃ (LSC), La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O₃ (LSCF), or Pt counter anode was formed on the backside of the YSZ electrolyte. A thin dense film of SDC (thickness = ca. 1 μ m) was attached on one side of YSZ surface before coating the LSC or LSCF anode. This SDC interlayer prevents unfavorable solid-state reactions between the LSC and YSZ. The steady state IR-free polarization characteristics of the electrodes were measured by a current-interruption method by using the Pt/air reference electrode.

Figure 1 shows changes of IR-free cell voltage (E_{ele}), IRloss of the cell (E_{IR}), and the applied terminal voltage including the IR-loss ($E_{app} = E_{ele} + E_{IR}$) as a function of $P[H_2O]$ (H₂ balance) at the Ni-dispersed SDC cathode operated at 0.52 A cm⁻² and 900°C. The E_{ele} decreases with $P[H_2O]$ due to an increased transfer rate of water vapor the reaction sites. However, the IR-loss was found to be increased with $P[H_2O]$, *i.e.*, increase in the equilibrated $P[O_2]$ in H₂O and H₂ mixture. Such an increase in the IR-loss is certainly ascribed to a decrease in the n-type electronic conductivity in the mixedconducting SDC. Thus, the applied voltage including the IR-loss, $E_{app} = E_{ele} + E_{IR}$, almost levels off at the minimum value at $P[H_2O] > 0.4$ atm.

Figure 2 shows the IR-free polarization curves for the LSC or LSCF anode (in O_2) and the Ni-dispersed SDC cathode (in $H_2 + H_2O$, $P[H_2O] = 0.4$ atm) at 900°C. It is seen that the performance of LSC and LSCF anodes were almost the same. For example, at 0.50 A cm⁻², the IR-free potential at the LSC and LSCF anodes was only 0.14 V vs. air reference electrode. Thus, the IR-free applied cell voltage was just 1.20 V at 0.50 A cm⁻².

The area-specific ohmic resistance of the present cell was found to be large, which was ascribed to a contact resistance between oxide (SDC, LSC or LSCF) particles and one at the interface of YSZ or YSZ/SDC interlayer. If the YSZ electrolyte with the thickness of 50 μ m were employed in our cell, the applied voltage including the IR-loss may become about 1.5 V (energy conversion: 97 %, HHV-base) even with the present contact resistances. Hence, our next target is to reduce the contact resistance by optimizing the electrode microstructure, which is also a key technology to improve the electrode performances.

References

- 1. M. Watanabe, H. Uchida, M. Shibata, M. Mochizuki, and K. Amikura, *J. Electrochem. Soc.*, **141**, 342 (1994).
- 2. H. Uchida, S. Arisaka, and M. Watanabe, *J. Electrochem. Soc.*, **149**, A13 (2002).
- 3. H. Uchida, S. Suzuki, and M. Watanabe, *Electrochem. and Solid-State Lett.*, **6**, A174 (2003).



Fig. 1 Changes of IR-free cell voltage (E_{ele}), IR-loss of the cell (E_{IR}), and the applied terminal voltage including the IR-loss ($E_{app} = E_{ele} + E_{IR}$) as a function of $P[H_2O]$ at the cathode. Cell temperature= 900°C, j = 0.52 A cm⁻².



Fig. 2 IR-free polarization curves for the LSC and LSCF anodes (in O_2) and the Ni-dispersed SDC cathode (in $H_2 + H_2O$, $P[H_2O] = 0.4$ atm) at 900°C.