High Power Low Temperature 3-D Bilayer Nanostructured Solid Oxide Fuel Cell

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Fuel cells are electrochemical energy conversion devices that transform the energy stored in the chemical bonds of fuel molecules into electrical energy. Among various kinds of fuel cells, solid oxide fuel cells (SOFCs) have attracted attentions due to its high energy conversion efficiency (i.e., chemical to electricity efficiency of 45-65 %) without limitation by the Carnot constraint, and fuel flexibility from hydrogen to conventional hydrocarbon fuels. [1-4] However, their high operating temperature (800-1000 °C) poses serious challenges for practical applications in structural and thermal stability, material compatibility for fuel cell components, and high fabrication cost. Therefore, many studies focused on lowering the high operating temperature of SOFCs to intermediate (500-800 °C) and further to low temperature (<500 °C) regime. At low temperatures, since both sintering and radiative heat transfer exponentially decrease, primary performance degradation mechanisms and insulation costs are reduced, which are critical parameters for portable applications of SOFCs. However, low operating temperature in turn increases losses (i.e., ohmic loss and polarization loss) in fuel cell operation, and thus the fuel cell performance drops off.

Representative approaches to reduce a polarization loss include enhancing catalytic activity at electrode and increasing the surface reaction area. [ref] It has been reported that catalytic interlayers such as doped CeO_2 or doped Bi_2O_3 enhance the surface kinetics at the cathode side. Therefore, we can lower the polarization loss significantly and improve the power density by employing catalytic interlayers. Furthermore, 3D-structuring of the MEA also improves fuel cell performance due to reduced polarization loss by larger surface reaction area. Especially, nanostructuring MEA using nanosphere lithography (NSL) has been shown advantageous compared to using conventional photolithography in terms of process cost and compatibility to physical deposition methods. However, thin-film LT-SOFCs utilizing all the advantages mentioned above, thus showing high power density (>1W/cm^2) at below 500 °C, have not been reported so far.

In this study, we present a nanostructured thin film LT-SOFC with bilayer electrolyte, which delivers high power density at below 500 °C. By nanostructuring MEA using NSL, the surface reaction area doubled with respect to the projected area. Also YDC catalytic interlayer at cathode interface reduced the polarization loss by ~35% compared to YSZ-only electrolyte cell. As a result, we were able to achieve maximum power densities of 1.3 W/cm^2 at 450 °C. To our knowledge, this is the one of the highest power density for LT-SOFCs reported to this point. This result will provide opportunities for wider applications (e.g., portable applications) of SOFCs.

References

[1] Steele, B. C. H.; Heinzel, A. Materials for Fuel-Cell Technologies. Nature 2001, 414, 345–352.
[2] Yamamoto, O. Solid Oxide Fuel Cells: Fundamental Aspects and Prospects. Electrochem. Acta 2000, 45, 2423–2435.
[3] Minh, N. Q. Solid Oxide Fuel Cell Technology;Features and Applications. Solid State Ionics 2004, 174, 271–277.
[4] Park, S.; Vohs, J. M.; Gorte, R. J. Direct Oxidation of Hydrocarbons in a Solid-Oxide Fuel Cell.Nature 2000, 404, 265–267.