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Structural and electrochemical properties of interconnect integrated solid oxide fuel cell

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ABSTRACT

Interconnect integrated solid oxide fuel cells (II-SOFC) have remaining design and process issues due to their differences in thermal and mechanical properties between metal and non-metal materials. In this work, a lightweight design of an II-SOFC using metal foam and a high temperature sinter-joining process, which is one of the less expensive fabrication methods, is proposed for mobile and automotive applications, and the electrochemical performance is evaluated. 8 mol% of Y_2O_3 stabilized ZrO_2 (8YSZ) is used as electrolyte and NiO/8YSZ as anode material. $Ce_{0.9}Gd_{0.1}O_{1.9}$ (CGO91) and $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-d}$ (BSCF)/$Sm_{0.2}Ce_{0.8}O_{1.9}$ (SDC) are used as the in-situ buffer layer and in-situ composite cathode, respectively; to avoid oxidation of the metal interconnect, no additional sintering process is employed. A very strong bonding property is achieved at the ceramic-metal interface; the cell has a maximum power density of 0.37 W cm^{-2} at 800 °C in hydrogen operating conditions.

1. Introduction

For use in auxiliary power unit (APU) applications, metal supported solid oxide fuel cells (M-SOFC) have been actively studied to obtain enhanced mechanical strength, sealing efficiency, and quick startup compared to the characteristics of conventional ceramic-supported SOFCs. However, one of the main problems of M-SOFCs is their complicated fabrication process. For example, combining metal and ceramic parts for an M-SOFC is a severe technological obstacle due to the differences in thermal and mechanical properties. For M-SOFCs, the metal part should be oxidation resistant, have good gas transport properties, and show a small coefficient of thermal expansion. Lee et al. [1] and Hui et al. [2] used stainless steel STS430 plates as a support for single cells in SOFCs. Stainless steel and Hastelloy X have been widely used as metal support by several research groups [3–11]. Cho and Joo [12,13] demonstrated the feasibility of Ni powder as a support material. However, the processes involved are expensive and cannot be scaled up to cells with relatively large area.

Another area of interest is lightweight, high power density SOFC stacks, which can be realized through interconnect integrated SOFCs using an alloy foam and the sinter-joining process. The alloy foam is used as an interconnect as well as a metal support; a fully sintered anode body with an electrolyte is sinter-joined with the alloy foam without using an expensive coating process. Therefore, adoption of the alloy foam as an interconnect and cell supporting metal part can lead to good characteristics such as gas transport and light weight. In this study, the fabrication of interconnect integrated SOFCs (II-SOFC) using alloy foam was carried out and the electrochemical properties of the II-SOFCs were investigated for application in automobiles.

2. Experimental

For the fabrication of interconnect integrated Solid Oxide Fuel Cells (II-SOFCs), a fully sintered anode supported ceramic cell comprised of 8 mol% Y_2O_3 stabilized ZrO_2 (8YSZ, Tosoh) electrolyte and a NiO/8YSZ anode without cathode layer was used. $Ce_{0.9}Gd_{0.1}O_{1.9}$ (CGO91, Praxair, USA) as an in-situ buffer layer

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was screen-printed onto the 8YSZ electrolyte. It should be noted that the term "in-situ" in this paper indicates that the coating process was carried out without heat treatment.

In case of the cathode preparation for the II-SOFCs, $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-d}$ (BSCF, surface area of 4.2 $m^2 g^{-1}$, Fuel Cell Materials) and $Sm_{0.2}Ce_{0.8}O_{1.9}$ (SDC, surface area of 212 $m^2 g^{-1}$, Fuel Cell Materials) were mixed in proportions of 70 wt.% and 30 wt.%, respectively [14]. The cathode inks for screen printing were fabricated using the cathode powders with acetone and a binder system comprised of α-terpineol and KD-1. BSCF/SDC composite cathodes mixed with ink vehicle systems were used as an in-situ operated cathode that was screen-printed onto a buffer layer (CGO91) on top of the electrolyte.

Alloy foam (ALANTUM, Korea) with a porous structure of 450 μm mesh was used as the metal interconnect and metal support for the fabrication of the II-SOFCs. An interconnect integrated cell was fabricated using a high temperature sinter-joining process [15,16]. A fully sintered anode-supported ceramic body consisting of an anode and an electrolyte was bonded to the alloy foam with the addition of a bonding layer. The composition of the bonding slurry, which was compatible with the high temperature sinter-joining, consisted of Ni-Cr-Fe powder (325-mesh, 72:14–17:6–10 wt.%, Alfa Aesar, USA), 8YSZ (d50: 0.4 μm, Tosoh, Japan), NiO (d50: 3.0 μm, J.T. Baker, USA) and graphite (d50: 20 μm). Solvent, binder, plasticizer, and dispersant were included as additives. The graphite accounted for 5 wt.% of the mix; it operated as a pore-former for gas diffusion purposes.

To prevent oxidation of the metal part, the sinter-joining process for the interconnect integrated cell was performed at 1400 °C in a reducing atmosphere of 4% H_2/96% Ar.

The microstructure of the fabricated cell was observed using scanning electron microscopy (SEM, Hitachi, S4300). An AC four-probe method using a Solartron 1287/Solartron 1260 (electrochemical interface/impedance, gain-phase analyzer) was used to measure the impedance property and current density–voltage–power density (I–V–P)

3. Results and discussion

Fig. 1a shows the front surface of the fully sinter-joined interconnect integrated cell comprised of the 8 mol% Y_2O_3 stabilized ZrO_2 (8YSZ) electrolyte, Ni/8YSZ anode, bonding layer, and alloy foam with area of 50 × 50 mm^2. The manufactured cell has a gray color, which indicates that elements in cell were fully reduced during the sintering processes. Especially, when dropping water on the surface of the outermost layer, 8YSZ, water droplets maintained the form of rectangles, they were not absorbed into the ceramic, implying that the 8YSZ electrolyte layer maintains a dense layer without being affected by the fabrication environment. On the other hand, Fig. 1b shows the back side alloy foam substrate, which has a porous structure; sprayed water was absorbed in a flash as soon as it hit the surface. In addition, Fig. 1c provides a cross-sectional image of the fully sintered interconnect integrated cell and two layers of the alloy foam and ceramic part (the fully sintered Ni/8YSZ anode after 8YSZ electrolyte coating), which are perfectly combined. Fig. 1d shows a fully sinter-joined metal-supported button cell with in-situ $Ce_{0.9}Gd_{0.1}O_{1.9}$ (CGO91) buffer layer and in-situ cathode layer.

Fig. 2 shows scanning electron microscope (SEM) images of the alloy foam and the fully sinter-joined cell. Fig. 2a shows the microstructural properties of the alloy foam used as the interconnect in the cell; the alloy foam maintains a porous structure with a net shape with a thickness of 1.5 μm. Fig. 2b provides microstructural images of the anode supported cell, bonding layer, and alloy foam, after being heat-treated at 1400 °C in a reducing atmosphere of 4% H_2/96% Ar. The highly porous structure of the alloy foam is

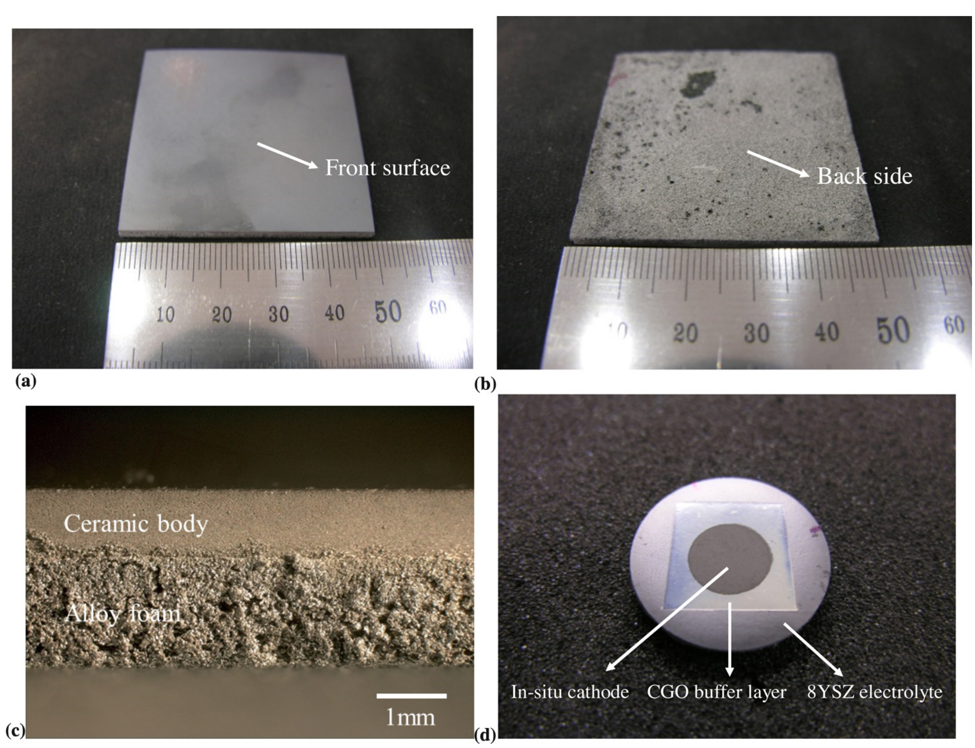

Fig. 1. (a) Sinter-joined metal alloy foam-supported cell with area of 50 mm × 50 mm, (b) back side of fabricated cell, (c) cell cross-sectional image, and (d) fully sinter-joined metal-supported single cell with in-situ CGO91 buffer layer and in-situ BSCF cathode layer.