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Screen-printed thin YSZ films used as electrolytes for solid oxide fuel cells

Xiaodong Ge [a], Xiqiang Huang [a,*], Yaohui Zhang [a], Zhe Lu [a], Jiahuan Xu [a], Kongfa Chen [a], Dawei Dong [a], Zhiguo Liu [a], Jipeng Miao [a], Wenhui Su [a,b,c]

[a] *Center for Condensed Matter Science and Technology, Harbin Institute of Technology, Harbin 150001, People's Republic of China*
[b] *Department of Condensed Matter Physics, Jilin University, Changchun 130022, People's Republic of China*
[c] *International Center for Material Physics, Academia, Shenyang 110015, People's Republic of China*

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Abstract

A thin yttria-stabilized zirconia (8 mol% YSZ) film was successfully fabricated on a NiO-YSZ anode substrate by a screen-printing technique. The scanning electron microscope (SEM) results suggested that the YSZ film thickness was about 31 μm after sintering at 1400 °C for 4 h in air. A 60 wt% $La_{0.7}Sr_{0.3}MnO_3$ + 40 wt% YSZ was screen-printed onto the YSZ film surface as cathode. A single cell was tested from 650 to 850 °C using hydrogen as fuel and ambient air as oxidant, which showed an open circuit voltage (OCV) of 1.02 V and a maximum power density of 1.30 W cm^{-2} at 850 °C. The OCV was higher than 1.0 V, which suggested that the YSZ film was quite dense and that the fuel gas leakage through the YSZ film was negligible. Screen-printing can be a promising method for manufacturing YSZ films for solid oxide fuel cells (SOFCs).

Keywords: Solid oxide fuel cells; Screen-printing; YSZ films

1. Introduction

In recent years, solid oxide fuel cells (SOFCs) have attracted more and more attention, due to their advantages of: high energy conversion efficiency, low pollution, fuel flexibility, etc. [1–5]. Yttria-stabilized zirconia (YSZ) has been widely used as the electrolyte for SOFCs because of its unique combination of properties such as high chemical and thermal stability, and pure ionic conductivity over a wide range of conditions [8]. Conventional YSZ-supported SOFCs are usually operated at about 1000 °C. However, such a high operating temperature has led to many problems, such as electrode sintering, interfacial diffusion between electrolyte and electrodes and mechanical stress due to different thermal expansion coefficients [6,7]. If the YSZ thickness can be reduced, the SOFC operating temperature can be lowered and the above problems may be solved. So at present many researchers have focused their study on how to make thin YSZ films.

There have been several successful methods reported to fabricate thin YSZ films, including electrochemical vapor deposition (EVD) [9], chemical vapor deposition (CVD) [10], sol–gel processing [11], spray pyrolysis [12], and so on. Compared with these methods, screen-printing is a cost-effective route, being easy to use and suitable for mass production [8]. Many research groups have prepared their SOFC electrodes by screen-printing [15–22], and this technique has been successfully adopted to fabricate SDC ($Sm_{0.2}Ce_{0.8}O_{1.9}$) and YDC ($Ce_{0.8}Y_{0.2}O_{1.9}$) membranes [13,14]. However, to our knowledge, there are few papers which report SOFC performance with a YSZ film fabricated by screen-printing.

In this paper, we developed a screen-printing method to fabricate YSZ films on NiO-YSZ substrates and the cell performance has been investigated.

2. Experimental

YSZ powder bought from Tosoh Corporation, NiO powder and flour were mixed thoroughly in a weight ratio of 5:5:1. The flour was used as a pore former. The mixed powder was then pressed into pellets (13 mm in diameter, 0.5 mm in thickness)

* Corresponding author. Tel.: +86 451 8641 8420; fax: +86 451 8641 2828.
E-mail address: huangxq@hit.edu.cn (X. Huang).

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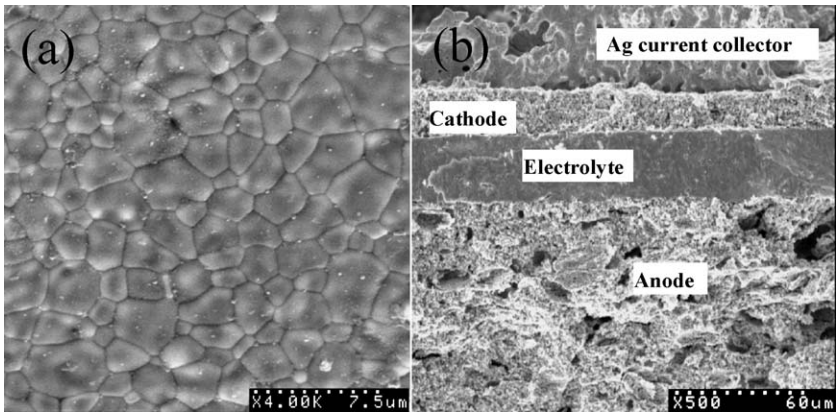

Fig. 1. SEM results of the post-test cell: (a) the surface of YSZ film and (b) cross-sectional view of the cell.

under a pressure of 350 MPa. Then the pellets were sintered at 1000 °C for 2 h.

To prepare YSZ films, YSZ powder was ball-milled for 13 h with ethanol added. A mixture of ethyl cellulose and terpineol was used as an organic vehicle. The ball-milled YSZ powder (60 wt%) was mixed with the organic vehicle (40 wt%) in an agate mortar and ground to obtain a homogeneous printing ink. The ink was then screen-printed onto the NiO-YSZ substrate to get a YSZ green film, and then the anode-supported green film was sintered at 1400 °C for 4 h with a heating rate of 1 °C min^{-1}.

$La_{0.7}Sr_{0.3}MnO_3$ (LSM) powder was mixed with YSZ powder in a ratio of 50/50 wt%. The LSM/YSZ powder was mixed with an organic vehicle to form a paste. The paste was screen-printed onto the sintered YSZ film and then sintered at 1200 °C for 2 h.

The single cell was tested from 650 to 850 °C with hydrogen as fuel and ambient air as oxidant, respectively. Solartron SI 1287 and Solartron SI 1260 were employed to measure the cell performance. The microstructure of the post-test cell was examined using a scanning electron microscope (SEM).

3. Results and discussion

3.1. Microstructure of post-test cell

Fig. 1(a) shows the surface of the supported YSZ film and Fig. 1(b) shows the cross-sectional view of the cell. As shown in Fig. 1(a), the irregular YSZ particles are arranged tightly with an average particle size of about 2.5 μm. From Fig. 1(b), it can be seen that the YSZ film was crack-free, continuous and quite dense with a thickness of about 31 μm. There was no obvious cracking or delamination of the YSZ film. Both the anode and the cathode well adhered to the YSZ film.

3.2. Cell performance

Fig. 2 shows the cell performance from 650 to 850 °C. Hydrogen and ambient air was used as fuel and oxidant, respectively. The open circuit voltages (OCVs) changed in a region of 1.02–1.08 V which were all higher than 1.0 V in the testing temperature range. Such high OCV values suggested that the YSZ electrolyte film was quite dense. The maximum power densities were 0.158, 0.318, 0.584, 0.964 and 1.30 W cm^{-2} at 650, 700, 750, 800 and 850 °C, respectively. In the *I–V* curves, some positive curvatures and negative ones were observed which usually corresponded to electrode polarization and concentration polarization, respectively [5]. From 650 to 750 °C, the cell exhibited obvious electrode polarization, which badly affected the cell performance. The concentration polarization was observed at 850 °C when the current density was higher than 4 A cm^{-2}.

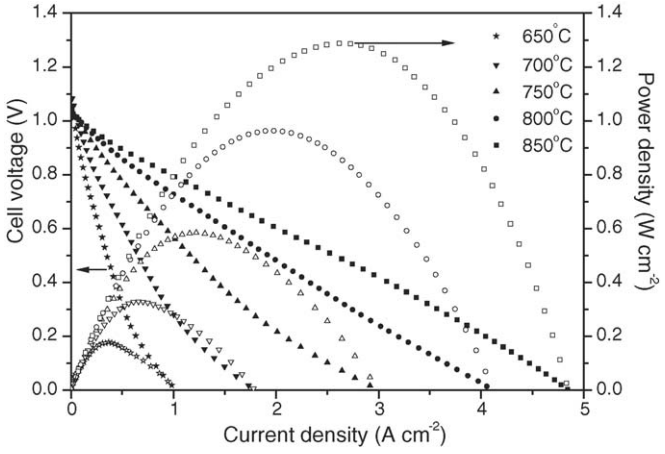

Fig. 2. *I–V* and *I–P* curves of the cell from 650 to 850 °C. Hydrogen and ambient air was used as fuel and oxidant, respectively.

4. Conclusions

Dense YSZ electrolyte films were successfully prepared on porous NiO-YSZ substrates by a screen-printing technique. The crack-free and dense YSZ films adhered to the electrodes well. The anode-supported cell based on a 31-μm-thick YSZ electrolyte film exhibited maximum power densities of 0.158, 0.318, 0.584, 0.964 and 1.30 W cm^{-2} at 650, 700, 750, 800 and 850 °C, respectively. Our initial results suggested that screen-printing is a promising technique for YSZ electrolyte film fabrication. More detailed investigations on screen-printing will be done in our future studies.

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