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Short communication

Testing of a cathode fabricated by painting with a brush pen for anode-supported tubular solid oxide fuel cells

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ABSTRACT

We have studied the properties of a cathode fabricated by painting with a brush pen for use with anode-supported tubular solid oxide fuel cells (SOFCs). The porous cathode connects well with the electrolyte. A preliminary examination of a single tubular cell, consisting of a Ni–YSZ anode support tube, a Ni–ScSZ anode functional layer, a ScSZ electrolyte film, and a LSM–ScSZ cathode fabricated by painting with a brush pen, has been carried out, and an improved performance is obtained. The ohmic resistance of the cathode side clearly decreases, falling to a value only 37% of that of the comparable cathode made by dip-coating at 850 °C. The single cell with the painted cathode generates a maximum power density of 405 mW cm^{-2} at 850 °C, when operating with humidified hydrogen.

1. Introduction

The solid oxide fuel cell (SOFC) is a completely solid device that converts the chemical energy of fuels to electricity by electrochemical oxidation. It has emerged as one of the most important power generation devices because of its high energy conversion efficiency, low noise and low pollution [1–3], and its ability to be used with many different fuels [4]. There are two main designs of SOFC: planar and tubular. Tubular SOFCs have many advantages [5–8] such as the ease of sealing, and their ability to endure the thermal stress caused by rapid heating up to the operating temperature, as reported by Kendall and Palin [6] and Yashiro et al. [7] for micro-tubular SOFCs. Tubular SOFCs can therefore be expected to be used for co-generation and transportation applications. The ohmic resistance of the cathode/electrolyte interface dominates the total ohmic resistance of the anode-supported tubular SOFCs [9]. Accordingly, the cathode needs to be optimized first in order for the SOFC to have the potential for commercial application at intermediate temperatures.

Sr-doped lanthanum manganate $La_{1-x}Sr_xMnO_3$ (LSM) is the classic cathode material for high-temperature solid oxide fuel cells (SOFCs) because of its good properties, such as electrical conductivity, catalytic activity for oxygen reduction, thermal and chemical stability at high temperature, and compatibility with electrolytes such as yttria-stabilized zirconia (YSZ) and doped ceria (DCO) [10]. However, LSM exhibits negligible ionic conductivity and high activation energy for oxygen dissociation, so there is some limitation in the use of pure LSM in cathodes for SOFCs operating at intermediate temperatures (600–800 °C). The LSM-based composite cathode is one where an ionic conductor is added to the LSM, leading to a significant decrease in the polarization resistance. For instance, Murray and Barnett [11] reported that at 700 °C, the polarization resistance is 7.28 Ω cm^2 for a pure LSM cathode but 2.49 Ω cm^2 for a LSM–YSZ composite cathode.

Cathode fabrication is a major focus for improving performance and reducing cost. Many methods for fabricating cathodes for anode-supported tubular SOFCs have been reported in recent years including dip-coating [9,8,12–15], atmospheric plasma-spraying [16,17], and the doctor-blade method [18]. However, they have a number of shortcomings. For example, with the dip-coating method it is difficult to control the thickness or weight of the cathode and the atmospheric plasma-spraying method requires high investment in large equipment and has complicated fabrication processes.

In this study, we describe painting of the cathode by a brush pen, a new method for fabricating the cathode of anode-supported tubular SOFCs. It has many advantages over conventional processes such as dip-coating, plasma-spraying and the doctor-blade method. First of all, it needs no large equipment or significant control of ambience conditions so the fabrication cost is very low. Secondly, it is a simple fabrication process and easy to carry out. Thirdly, it is easy to control the thickness or weight of the cathode. Finally, it can be applied to both laboratory and industry scale by reason of the advantages listed above.

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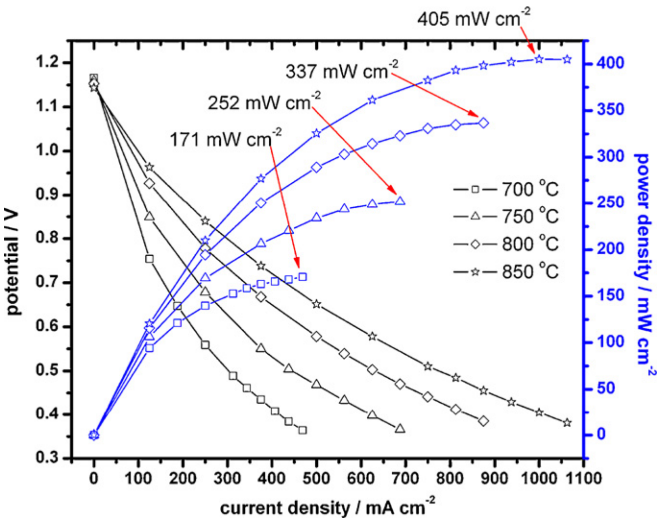

Fig. 1. The typical curves for potential and power density versus the current density for the tubular SOFC with a painted cathode at different temperatures while running on humidified hydrogen.

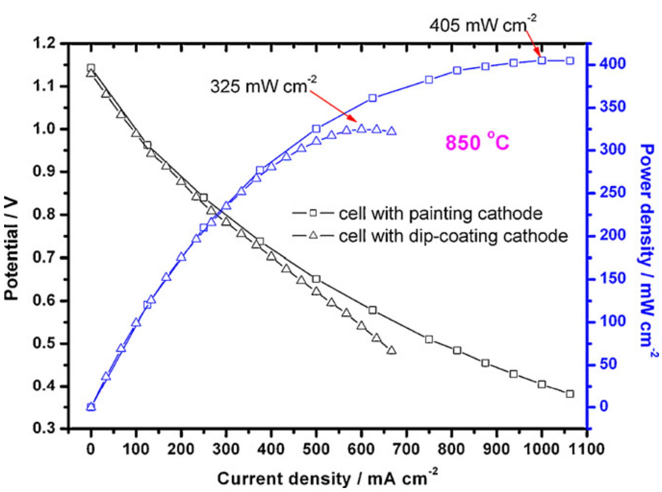

Fig. 2. The comparison of the *I–V* and *I–P* curves for tubular cells using cathodes prepared by the two methods at 850 °C while running on humidified hydrogen.

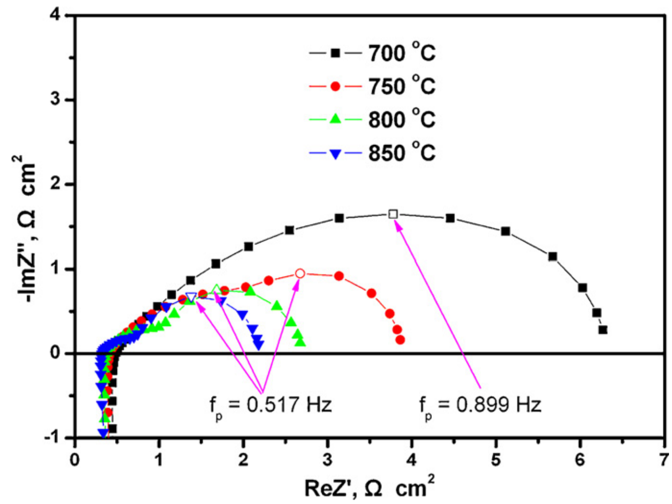

Fig. 3. AC impedance spectra for the cell with a painted cathode under open circuit at different temperatures using humidified H_2 as fuel and O_2 as oxidant.

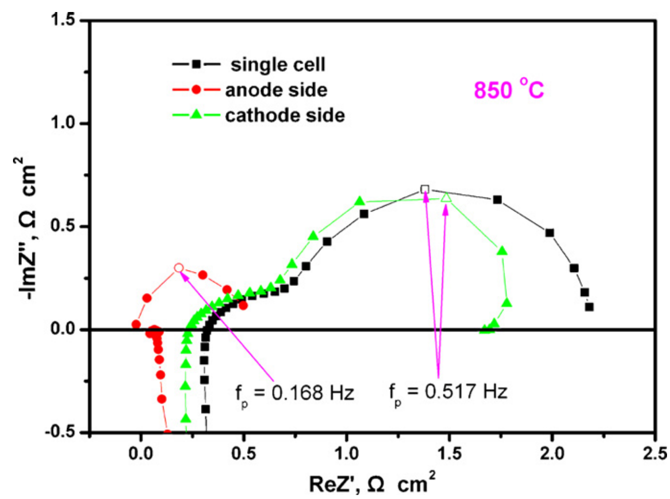

Fig. 4. AC impedance spectra for the single cell, the anode side and the cathode side under open circuit at 850 °C using humidified H_2 as fuel and O_2 as oxidant.

2. Experimental

2.1. Fabrication of tubular SOFCs

The anode-supported thin electrolyte tube, consisted of a NiO–YSZ anode support tube, a NiO–$Zr_{0.89}Sc_{0.1}Ce_{0.01}O_{2-x}$ (ScSZ, scandia-stabilized zirconia, Daiichi Kigenso Kagaku Kogyo, Japan) (NiO–ScSZ) anode functional layer, and a ScSZ electrolyte film, was first obtained using dip-coating and co-sintering techniques [9]. The length of the tube was approx. 10.8 cm and the outside diameter of the tube was approx. 1.0 cm.

Next, the anode tube with electrolyte was painted with cathode ink by a brush pen. The cathode ink consisted of $(La_{0.8}Sr_{0.2})_{0.98}MnO_3$ (LSM, lanthanum strontium manganite, Inframet Advanced Materials, CT, USA) and ScSZ powder, and terpineol, ethyl-cellulose and other organic ingredients. After painting the cathode ink, the tube was dried in air and sintered at 1200 °C for 2 h in air to complete a cell. The area of the cathode was approximately 10.0 cm^2.

2.2. Cell performance test

Tubular SOFC tests were carried out in a single-cell test setup, whose details are reported elsewhere [9]. Humidified hydrogen was used as fuel and oxygen was used as the oxidant. The fuel and oxidant flow rates were controlled at 180 mL min^{-1} and 120 mL min^{-1}, respectively. The current–voltage (*I–V*) curves and electrochemical

Table 1
Maximum power densities (MPD), ohmic resistances (R_Ω) and electrode polarization resistances (R_E) of cell and cathode of the anode-supported tubular SOFC at 850 °C using a painted cathode compared to those with a dip-coated cathode.

	MPD (mW cm^{-2})	R_Ω of cell (Ω cm^2)	R_E of cell (Ω cm^2)	R_Ω of cathode (Ω cm^2)	R_E of cathode (Ω cm^2)
Dip-coated cathode	325	0.72	0.80	0.62	0.68
Painted cathode	405	0.32	1.86	0.23	1.46