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High performance anode with dendritic porous structure for low temperature solid oxide fuel cells

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ABSTRACT

A dendritic porous supported microstructure simultaneously creates small pore size and broad gas diffusion pathways in a solid oxide fuel cell anode membrane. This microstructure also achieves pore sizes that reduce with increasing depth within the membrane without increasing the structure tortuosity. Such a microstructure supplies high triple phase boundary density, fast gas diffusion and low polarization resistance. Here we characterise the performance of a porous anode with such a dendritic microstructure. The solid oxide fuel cell with this high performance anode achieved 0.92 W cm^{-2} power density at 600 °C.

Introduction

Recent studies of solid oxide fuel cells (SOFCs) have aimed to improve their output power density at low operating temperature (≤600 °C) [1–4]. Extensive efforts have been made to develop high-performance cathode materials and microstructures [1,5]. Recent studies have also found that optimisation of the anode microstructure can significantly affect the power density of SOFCs at low temperatures [6]. An ideal anode microstructure needs to contain a high density of triple phase boundaries (TPB) and broad gas diffusion pathways for the reduction of electrochemical polarization resistance and concentration polarization resistance. It is well known that the electrochemical reactions predominantly occur at the TPBs that are very close to the electrode/electrolyte interface [7–9]. A porous anode support with small pore sizes is thought to increase the TPB density; however, it will also significantly reduce the gas diffusion rate. A graded porous structure has been fabricated using a tape casting method in order to improve the gas diffusion [10,11]. It demonstrated a two-layer structure: small pore size (~1 μm diameter) in the reaction region and large pore size (~5 μm diameter) in the rest of the anode support [11]. However, using conventional methods, such as tape casting, screen printing or spray coating, it is not easy to maintain a porous structure with low tortuosity, high

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porosity and high mechanical strength simultaneously in this graded structure because it is almost impossible to control the transition between the pores and how they are connected during these fabrication processes. This results in randomly stacked pores and increases the tortuosity of the microstructure. The mechanical strength of the layered structure is also likely to be adversely affected by thermal expansion mismatch.

In our previous work, we developed a microchanneled membrane structure and it has been used in oxygen permeation membranes, SOFC and SOEC structures [12–15]. We showed that the microchanneled structure provided a fast gas diffusion rate because of the straight and broad microchannels [15,16]. Recently, we have further developed a dendritic microchanneled structure. In this structure the microchannels gradually split from 100 μm diameter into numerous tiny microchannels the diameters of a few microns [17]. However, in this dendritic microchanneled membrane structure, the microchannel split/merge structure almost disappears in the region close to the porous support/dense layer interface and this prevents the surface area from being further increased in the interface region. This is not advantageous for SOFC applications because the pore size is too large (few microns) to create a large surface area and extended TPB length in the electrode/electrolyte interface region.

Here, we demonstrate a new dendritic porous microstructure with an improved porous electrode/electrolyte interface. The pore size in the region of electrode/electrolyte interface reduced from a few microns into the submicron level, and therefore, significantly increased the TPB length in the interface region for SOFC applications. More specifically, in this structure, the pores merge with each other and gradually increase from submicron pores near the interface to microchannels with diameters of hundreds of microns near the exterior (Fig. 1a). The submicron level pore size in the anode/electrolyte interface satisfies the requirements of high surface area and TPB density for SOFC application. This microstructure was fabricated in a single step, mesh-guided phase inversion process, which avoids the thermal expansion mismatch of a layered structure because the pore size transition is continuous and smooth [17]. As a result, it demonstrated a high output power density of 0.92 W cm^{-2} at 600 °C.

Experimental

Our previous research specifically interpreted the fabrication process and formation mechanism [17]. The fabrication of the dendritic anode membrane was started with slurry preparation. 60 g NiO (average particle size ≤ 3 μm, J.T. Baker) and 40 g GDC (GDC10-TC, particle size D50 0.1–0.4 μm, Fuel Cell Materials, US) powder were mixed with 42.6 g 1-methyl-2-pyrrolidinone (NMP, 99%, Sigma-Aldrich), 7.6 g polyether

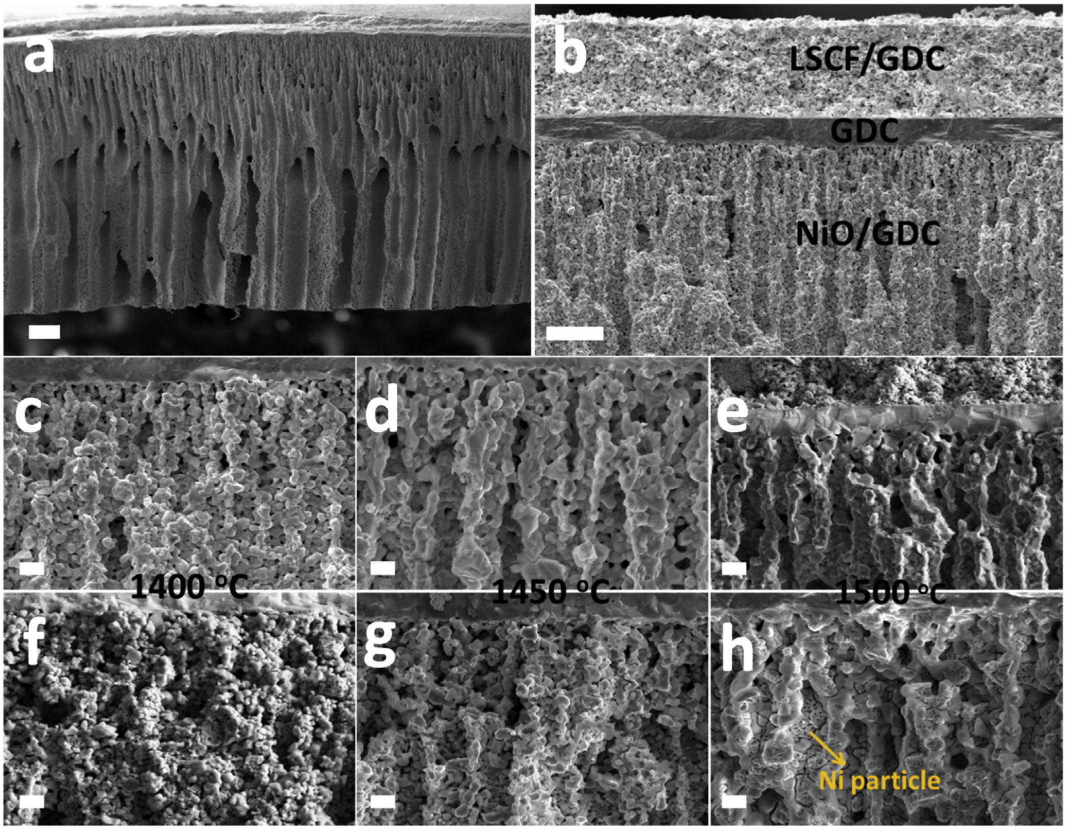

Fig. 1 – SEM images of the a) dendritic anode support, b) cathode/electrolyte/anode interface, c-e) as sintered anode/electrolyte interface, f-h) reduced anode/electrolyte interface. Samples c and f were sintered at 1400 °C; samples d and g were sintered at 1450 °C; samples e and h were sintered at 1500 °C. The scale bars in a and b are 100 μm and 20 μm, respectively. The scale bars in c-h are all 4 μm.

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