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Microarchitectured solid oxide fuel cells with improved energy efficiency (Part II): Fabrication and characterization

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HIGHLIGHTS

- Microarchitectured SOFCs are fabricated and characterized.
- Their performance improvement as predicted by our model in Part I is proved.
- Fabrication techniques involve sintering of a button cell and laser ablation.
- Current density and peak power density are increased by 17% and 19% over baseline.

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ABSTRACT

Part I of this study presented a computational model-based approach for enhancing the performance of solid oxide fuel cells (SOFCs) with designed microarchitecture. The performance of such SOFCs was predicted to greatly improve through a systematic computational design and optimization approach. Part II here proves through experimental fabrication and characterization that microarchitectured SOFC performance can be improved as predicted by the model. A real and specific SOFC is chosen, fabricated and characterized to demonstrate the proof-of-concept. Fabrication techniques using sintering and laser ablation are demonstrated. Pore size and geometry are characterized by interferometry-based surface profilometry and scanning electron microscopy. SOFC button cell performance testing including power output performance and electrochemical impedance spectroscopy are performed. The results show that SOFC performance in a microarchitectured cell can be improved over a baseline button cell by 9–17% in current density and by 7–19% in power density.

1. Introduction

In Part I of this study, the scientific basis of the motivation to improve SOFC performance by controlling the distribution of the electrode layer materials was presented. A concept incorporating conducting wires and designed porous channels in the electrodes was proposed for further investigation with the objective of achieving improved SOFC performance via improved transport of electrons, reactant and product gases. A fundamental computational model-based approach to enhance the performance of SOFCs with microarchitectured design was developed. The performance of microarchitectured SOFCs was optimized in order to achieve higher power density than currently attainable in state-of-the-art SOFCs.

Conventional techniques for fabricating SOFCs include chemical vapor deposition (CVD), physical vapor deposition (PVD), electrochemical vapor deposition (EVD), electrophoresis deposition (EPD), atmospheric plasma spraying (APS), vacuum plasma spraying (VPS), sputtering, flame coating, laser ablation, sol–gel coat, and ceramic forming techniques such as tape casting, tape calendaring, screen printing, and dry press formation [1–7]. These manufacturing techniques are not adequate for precise control over the orientation, placement, architecture, and distribution of conducting and porous pathways. In a majority of conventional techniques that are used to produce the films of SOFC materials, SOFC components are mixed with molten resin before processing, which causes tortuous porosity pathways and random distribution of electronically conducting networks in the electrodes. The fabrication of a SOFC with intentionally designed conducting wires and

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porous channels is nearly impossible using these techniques. Therefore, new and novel fabrication techniques that enable controlled distribution of SOFC materials are needed. Alternatively, additional fabrication processes should follow conventional techniques. In this study, anode-supported SOFC button cells are first fabricated by powder pressing and sintering. Laser ablation techniques are investigated to produce pore channels in the SOFC anode layer due to relatively easier fabrication. The simplest application of laser ablation is to remove material from a solid surface in a controlled fashion. Laser machining and particularly laser drilling are examples [8–13]; pulsed lasers can drill extremely small, deep holes through very hard materials.

The objective of Part II is to prove that the performance of microarchitectured SOFCs can be improved as predicted by the fundamental computational model. As a proof-of-concept, a real and specific SOFC is chosen, fabricated and characterized. SOFC button cell fabrication techniques using sintering and laser ablation is demonstrated. Pore size and geometry are characterized by interferometry-based surface profilometry and scanning electron microscopy. SOFC button cell performance testing is performed. This includes power output performance and electrochemical impedance spectroscopy.

2. Fabrication of anode-supported button cell

The fabrication of SOFC button cells consists of three main steps as follows.

2.1. Fabrication of NiO-YSZ anode supports

NiO and YSZ in a weight ratio of 65:35 with 5wt% corn starch are used as the raw materials. Starch is used as a pore former to enhance the porosity of the Ni/YSZ anode. Button anode supports are processed by pressing NiO-YSZ uniaxially under a pressure of 250 MPa using a 13 mm diameter die, and pre-calcined at 900 °C for 2 h in air.

2.2. Fabrication of YSZ membrane on anode supports

A thin YSZ electrolyte on the button NiO-YSZ anode supports is prepared by a refined particle suspension coating technique [14]. The YSZ suspension is prepared by dispersing 3 g YSZ (TZ-8Y Tosoh, Japan) powders in 30 g ethanol with a small amount of organic ingredients, such as binder and dispersant, added. The YSZ membrane is then prepared by drop-coating the YSZ suspension on the button anode. The thickness of the YSZ membrane is exactly controlled by the volume of drop-coating. The coatings are dried in air for several minutes without any heating or cooling process and they are then co-sintered at 1400 °C for 5 h. The heating rate is 1 °C/min before 550 °C and 2 °C/min from 550 to 1400 °C.

2.3. Preparation of cathode

Lanthanum strontium cobalt ferrite (LSCF) is used as the cathode. In order to avoid the reaction between LSCF and YSZ, a thin layer of $Sm_{0.2}Ce_{0.8}O_{1.95}$ (SDC) is used as the buffer layer, which is co-fired with LSCF at 1080 °C for 2 h. The cathode area is 0.3 cm^2.

The schematic of a fabricated anode-supported button cell with a 700 μm thick NiO-YSZ anode, a 15 μm thick YSZ electrolyte, a 2 μm thick SDC buffer layer, and a 50 μm thick LSCF cathode is shown in Fig. 1.

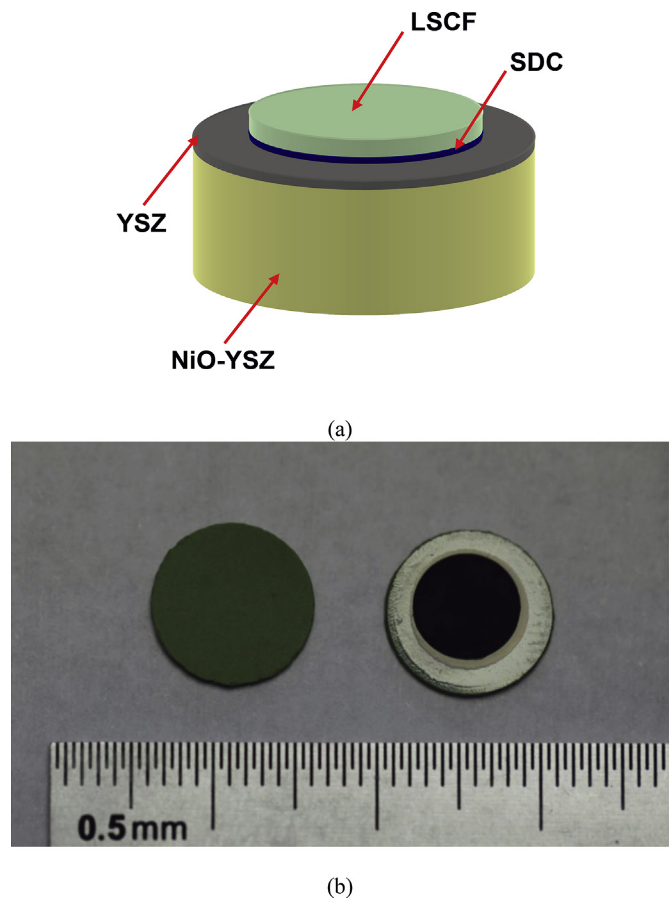

Fig. 1. (a) Schematic of anode-supported SOFC button cell and (b) actual fabricated button cell.

3. Fabrication of SOFC microarchitectures using laser ablation

3.1. Laser ablation

Laser ablation is the removal of material from a surface as a result of absorption of laser radiation. The depth over which the laser energy is absorbed, and thus the amount of material removed by a single laser pulse, depends on the material's optical properties and the laser wavelength. The simplest application of laser ablation is to remove material from a solid surface in a controlled fashion. Laser machining and particularly laser drilling are examples; pulsed lasers can drill extremely small, deep holes through very hard materials. A femtosecond laser is used to micromachine pore channels in the button cell. The laser ablation setup is as follows. A laser beam from a laser head is reflected by the reflection mirror and goes through a polarizer and a wave plate. The polarizer and the wave plate are used to adjust the laser power. After a beam splitter, 90% of the laser beam transmits and 10% is reflected to a power meter. The transmitted laser beam passes through a shutter which is used for controlling the exposure time. The laser beam is focused on the sample surface. In order to fabricate pore channel arrays of 20 × 20 in the sample, the sample is mounted on a 2-D stage to position the sample surface under the laser beam for each pore and to control the center-to-center distance between pore channels. The fabrication time per pore channel is 5s. Laser processing parameters used for experiments are listed in Table 1.