Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/he

Effect of cathode geometry on the electrochemical performance of flat tubular segmented-in-series(SIS) solid oxide fuel cell

Usman Mushtaq [a], Dae-Wi Kim [b], Ui-Jin Yun [b], Jong-Won Lee [a], Seung-Bok Lee [a], Seok-Joo Park [a], Rak-Hyun Song [a], Guntae Kim [c], Tak-Hyoung Lim [a,*]

[a] Fuel Cell Research Laboratory, Korea Institute of Energy Research (KIER), 152 Gajeong-ro, Yuseong-gu, Daejeon 305-343, Republic of Korea
[b] R&D Department, Inocat.Co. LTD., 152 Gajeong-ro, Yuseong-gu, Daejeon 305-343, Republic of Korea
[c] School of Energy and Chemical Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan 689-798, Republic of Korea

ARTICLE INFO

Article history:
Received 26 January 2015
Received in revised form
9 March 2015
Accepted 10 March 2015
Available online 2 April 2015

Keywords:
SIS SOFC
Flat tubular
Cathode geometry
Cathode polarization
Electrochemical performance

ABSTRACT

A flat tubular segmented in series (SIS)-SOFC was fabricated with variable cathode thicknesses and the performance characteristics were analyzed. Vacuum slurry dip coating and screen printing technique were employed to coat the NiO-Ce_1ScSZ_{10} anode, Ce_1ScSZ_{10} electrolyte, and $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}$ cathode on the extruded 3YSZ ceramic support. A sub module consisting of 5-cell with a total active electrode area of 4 cm^2 was interconnected in series using Ag-glass composite. Electrochemical performance analysis was conducted between 600 and 800 °C using 300 CC/min. 3 vol.% humidified hydrogen fuel and 1500 CC/min. air as oxidant. The results obtained from electrochemical impedance spectroscopy and current–voltage polarization curves revealed a 57 μm thick cathode layer as the optimum thickness. An application of LSCo as the cathode current collector on the surface of the cathode enhanced the performance by approximately 30% at 750 °C.

Introduction

Solid oxide fuel cells (SOFCs) are known to generate energy and have been investigated with much attention due to their higher efficiency, excellent heat utilization system integration, pollution free emissions, and fuel flexibility. However, the relatively high cost of SOFC still hinders its commercialization. Thus, alternate cheaper materials and low cost fabrication methods should also be focused on in order to enable SOFC to enter effectively into the real market, and compete with conventional energy generation technologies [1].

Development of new concept materials such as thin electrolyte membranes, and the incorporation of electrode materials of high electrochemical activity at low temperature are

* *Corresponding author*. Tel.: +82 42 860 3608; fax: +82 42 860 3297.
E-mail address: ddak@kier.re.kr (T.-H. Lim).
http://dx.doi.org/10.1016/j.ijhydene.2015.03.040
0360-3199/

effective approaches to lower the operation temperature and subsequently reduce the cost of SOFC so that interconnection, current collection and structural components can be made from relatively inexpensive new concept materials [2,3].

Fig. 1 illustrates the layout of a segmented-in-series (SIS) solid oxide fuel cell (SOFC) sub module in which flat tubular SIS-SOFC cells are arrayed as narrow strips on the surface of a porous ceramic support structure. Fuel flows through the flat tubular ceramic support and the cathode sides of the SIS-SOFC are exposed to air on the outer side [4]. Each unit cell contains an anode-electrolyte-cathode composite and an interconnect layer. The unit cell consists of a cermet anode (e.g. Nickel–scandia-stabilized zirconia, Ni–ScSZ), a dense electrolyte layer (e.g. ScSZ-GDC), and a composite cathode (e.g. LSCF-GDC, LSCF). The cathode in the present study is a bi-layered one with an LSCF current collection layer above an LSCF-GDC functional layer; both the layers are usually a few tens of microns in thickness. The thickness and the width of the porous ceramic substrate are usually on the order millimeters.

The above described SIS-SOFC has more attractive advantages than does a typical tubular SOFC in terms of performance and fabrication aspect, and in particular in terms of the associated geometrical features Geometrical benefits include unit cell interconnected electro-mechanically on the surface of the flat tubular ceramic support, enhancing fuel utilization. The design results in higher power density per unit volume and improves the simplification and practicality of the overall tubular SOFC.

There are two known geometrical structures of SIS-SOFC: tubular SIS-SOFC [5] and conical-shaped anode-supported SIS-SOFC. Tubular SIS-SOFC comprises a porous ceramic substrate with a tri-layer of anode/electrolyte/cathode; prolonged stability during coking and redox cycles due to an additional active barrier layer between the ceramic substrate and the anode is assured. Based on modeling and experimental efforts, Barnett et al. [5,12,25] achieved a somewhat increased power density by reducing the lateral resistance losses across the electrodes and maintaining large active cell area by lowering the cell width and interconnect area. Lai and Barnett [5] presented a model to analyze SIS-SOFC performance as functions of cell and interconnect geometry, support material, cell area-specific resistance (ASR), and electrode resistance. Their results also revealed that the cathode ASR can be somewhat reduced by applying a porous LSM current-collection layer above the cathode [14].

Alternately, Sui and Liu [6,7,11] proposed a design that can be stacked with multiple cone-shaped single anode-supported SOFC cells connected electrically with gas flow in series. Compared with the banded tubular SIS-SOFCs, conical SIS-SOFCs prepared on anode substrates decrease the concentration polarization at high current density by eliminating the insulating substrate. Moreover, cone-shaped anode-supported SIS-SOFC stacks may have smaller film resistance, reduced fabrication steps, and simpler processes. However, fuel leakage through interconnects has been observed to reduce the overall open circuit voltage (OCV) of such stacks; this leakage also induced a degradation of the long-term continuous operation of such SIS-SOFCs [13,15].

Among many issues associated with the performance enhancement of tubular SIS-SOFC, it is known that the cathode characteristics such as the thickness, the distribution of elements, the conductivity, the adaptation for the current collector, and the microstructure at the porous cathode are primary factors that govern SIS-SOFC performance, particularly in the case of banded type flat tubular SIS-SOFC. Performance loss of SIS-SOFC due to ohmic polarization can be reduced by increasing the thickness of the cathode and by application of an efficient current collector in the viewpoint of engineering endeavors. Whereas the performance enhancement of SIS-SOFC has been extensively studied [9,10,14], there have been relatively few systematic studies on the cathode geometric characteristics of banded type flat tubular SIS-SOFC despite its well-recognized importance. Therefore, in this work, a flat tubular SIS-SOFC sub module composed of a 5 unit cell was fabricated to analyze the basic cathode geometry; related variables were analyzed by combining experimental and theoretical approaches. The SIS-SOFC performance was relatively improved by increasing the thickness of the cathode

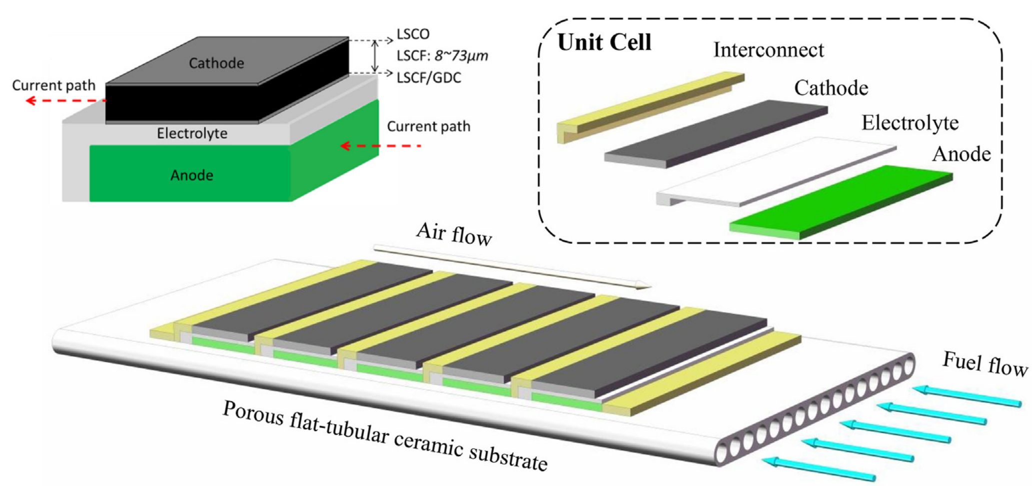

Fig. 1 – Flat tubular Segmented-In-Series (SIS) SOFC sub module and unit cell schematics.