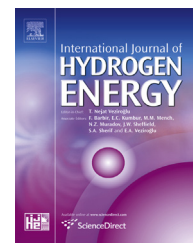


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Effects of fabrication parameters on the performance of solid oxide electrolyzer cell

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ABSTRACT

The microstructure has a great impact on the performance of solid oxide fuel/electrolyzer cells while the cell fabrication parameters mainly determine the microstructure of the cell components. In this study, a number of five-layered cells with 16 cm² active area are fabricated and the effects of several cell fabrication parameters including sintering temperature and electrode composition on the hydrogen production performance are investigated. The experimental results showed that the optimum sintering temperature of the electrolyte, cathode and anode should be 1400 °C, 1250 °C and 1075 °C, respectively, while the solid weight ratio of both NiO-ScSZ cathode and LSM-ScSZ anode functional layer should be 1:1. The optimized cell produces 38 Sccm H₂ at an operation temperature of 800 °C and 1.5 V. Then, the cell size is increased to a commercial size of 81 cm² active area. The final cell exhibits an acceptable H₂ production of 154 Sccm H₂ at 800 °C and 1.5 V. The relatively lower performance of the commercial-size cell is attributed to the inadequate current distribution/collection due to the increased surface area.

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Introduction

The increase in the world energy demand as a result of the population growth as well as technological developments necessitates new energy sources alternative to the finite fossil fuels polluting our environment and threatening our future. The renewable energy sources such as wind power and solar energy have therefore attracted considerable attention in recent years. The major drawback of these sources is that they need energy storage since they are intermittent. Therefore,

they are not suitable for the applications where the supply of continuous or instantaneous power is demanded. This problem can be solved by using batteries. However, besides the loss of charge with time, low storage capacity and short life, the batteries require high cost and large areas. Alternatively, hydrogen has a great potential as an alternative fuel or energy carrier. Especially after utilized by a fuel cell, the only byproduct is water. Although hydrogen is abundant in nature, it is not available in its pure state instead it can be found as a compound with other elements. Currently, hydrogen is produced via steam reforming of natural gas, which is neither

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clean nor renewable. On the other hand, water is also abundant in nature and can be split into hydrogen and oxygen through water electrolysis. This can be achieved via a reverse operation of low or high temperature fuel cells during which electricity, heat energy and water are supplied. The required heat energy can be obtained using the waste heat from any processes. The comparison of water electrolysis based on different fuel cell technologies was reported in the literature [1–3]. Among them, solid oxide electrolysis can be considered to be advantageous in that it can provide relatively high efficient hydrogen generation due to high operating temperatures, which improves the electrochemical reaction rates and reduces the electrical energy demand. The reports on the recent advances and technological developments of high temperature solid oxide electrolysis can be also found in the literature [4,5].

Since the solid oxide electrolyzer technology is still under development, the recent studies on the hydrogen generation via solid oxide water electrolysis mainly have focused on the material development for the anode [6–12], cathode [13–19], electrolyte [20–24], interconnect [25–27] and sealant [28–33] as well as the estimation of the cell performance via electrochemical modeling [34–40]. Oxygen/syngas production through carbon dioxide electrolysis using solid oxide electrolyzers is also possible and there can be found several reports in the literature on these topics [41–48]. The effects of operating conditions on the solid oxide electrolyzer cell (SOEC) were also investigated. Brisse et al. [49], for example, investigated the effects of the operating temperature, humidity and current density on the performance of a SOEC composed of Ni-YSZ anode support, YSZ electrolyte and LSM cathode. It was found that the cell performance tends to increase with increasing the operating temperature and absolute humidity. The open circuit potential, on the other hand, followed just an opposite trend. Especially, at moderate absolute humidities below 70 vol.%, the cell performance was shown to be limited by the gas diffusion in the cathode. A current density of 1.4 A cm^{-2} was reached at only 1.1 V when the absolute humidity and operation temperature was 82 vol.% and 900 °C, respectively. Similar improvements in the cell performance with the operating temperature and humidity results were also reported by Kim et al. [50]. They also showed that the effect of humidity on the cell performance becomes significant specifically at temperatures higher than 700 °C. A significant improvement in the SOEC performance with the operating temperature was also concluded by Kim-Lohsoontorn et al. [51] and Lee et al. [52]. Unlike Brisse et al. [49] and Kim et al. [50], Jin et al. [53] reported that an increase in the absolute humidity increases the cell resistance, thus lowers the cell performance.

Beside the operation conditions, the cell fabrication parameters are also significant since they determine the performance of the electrolysis cell. However, there exist limited studies on this topic and most of them considered pellet-size cells. Among them, Patro et al. [54] experimentally optimized the fabrication parameters of Ni-ScCeSZ cathode for SOEC application. The optimum sintering temperature, thickness and composition of the cathode were determined as 1300 °C, 35 μm and 60 vol.% NiO and 40 vol.% ScCeSZ, respectively. Uchida et al. [55] also focused on the cathode composition and

developed Ni-SDC by Ni infiltration as a cathode for SOEC application. The highest electrolysis performance was obtained from the cell, including 8 vol.% Ni infiltrated cathode. Wang et al. [56], on the other hand, applied a porous YSZ layer between the dense YSZ electrolyte and LSM-YSZ anode in Ni-YSZ cathode supported SOEC configuration. After the optimization of the pre-sintering temperature as 1200 °C and thickness of the YSZ electrolyte as 4 μm , 80% improvement in the electrolysis performance was reported due to the presence of the porous YSZ layer. The significant increase in the cell performance was attributed to the increased number of anode electrochemical reaction zone due to the penetrated LSM-YSZ anode into the porous YSZ layer. In this study, unlike the available literature, several fabrication parameters are considered and optimized by experimental investigations of their effects on the electrolysis performance of 16 cm^2 active area cells. After the optimizations, a cell with commercial size of 81 cm^2 active area is also fabricated and tested.

Experimental

Fabrication of solid oxide electrolyzer cells

The classical tape casting and screen printing techniques were used to fabricate the membrane electrode assembly (MEA) of the electrolyte supported cells with 16 cm^2 active area. MEA comprises five layers, namely cathode current collecting, cathode functional, electrolyte, anode functional and anode current collecting layers from cathode to anode in an order. Scandia stabilized zirconia (ScSZ) was selected as the electrolyte material due to its high ionic conductivity. ScSZ powders with 0.5–0.7 μm particle size (Nextech Materials, Ohio, USA) were mixed with organic dispersant (fish oil, Sigma–Aldrich, Munich, Germany), binder (butvar, Sigma–Aldrich), plasticizer (poly ethylene glycol, Sigma–Aldrich) and a combination of high purity ethanol and ethyl methyl ketone (both from Sigma–Aldrich) as a solvent. The mixture was ball milled for 24 h to obtain a tape casting electrolyte slurry. The slurry was then tape cast on a laboratory scale tape casting equipment with a blade gap of 170 μm . After drying in air atmosphere for 15 min and cutting with a utility knife, six tapes were stacked together. The first lamination was achieved by uni-axial press at 20 MPa pressure for 4 min. The lamination was completed after the isostatic pressing step performed at 60 °C and 50 MPa for another 4 min. The electrolyte laminate was then cut with a laser cutter in the sizes of 78 mm \times 78 mm prior to sintering. After the sintering at 1400 °C for 3 h, the outer sizes were reduced to 60 mm \times 60 mm and the thickness was measured as \sim 150 μm .

NiO–F powders with 1–2 μm particle size from Novamet (New Jersey, USA) were mixed with ScSZ powders at a weight ratio of 1:1, respectively. Suitable amounts of ethyl cellulose binder and terpineol solvent (both from Sigma–Aldrich) were then added. The mixture was ball milled for 12 h to prepare a printable NiO–ScSZ cathode functional layer ink. After the homogenization process through three-roll mill, the paste was screen printed on the electrolyte layer. Prior to screen printing of NiO cathode current collecting layer, the functional layer was dried in a furnace at 100 °C for 30 min. The screen

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