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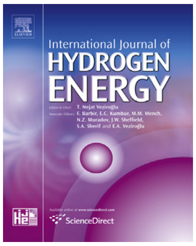

Effect of a shielded slot on a planar solid oxide fuel cell

Bong Hwan Choi, Hyung Jin Sung *

Department of Mechanical Engineering, KAIST 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

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ABSTRACT

A shielded slot was designed for use in a typical current collector/gas distributor fuel cell and was formed from a series of arches with heights suitable for providing sufficient quantities of fuel gases and reaction areas. The shielded slot was substituted in place of the interconnect and offered several advantages in terms of mechanical support and electrical contact. A three-dimensional (3-D) electrochemical reaction model and a microelectrode model of the planar solid oxide fuel cells (SOFC) were used to predict the performances of the shielded slots in planar SOFCs. Prior to analyzing the complex arrangement of the shielded slot, a variety of interconnect arrangements were simulated to understand the relationship between the gas supply and the electrical contact arrangements. The reactivity properties were examined and the most effective arrangement of shielded slots was identified in an effort to design an optimal shielded slot.

Introduction

Fuel cells are energy conversion devices that directly generate electrical power from the chemical energy of a fuel gas. Solid oxide fuel cells (SOFCs) generate low levels of pollutants, are highly efficient, offer fuel flexibility, and have several advantages over other electricity generation methods for a variety of purposes. The interconnect is an important component of a fuel cell stack and provides mechanical support and electrical connections between the anode and cathode plates. The interconnect is composed of a center plate, an anode shielded slot, and a cathode shielded slot. A shielded slot plate features a sheared corrugated trapezoidal pattern. The interconnect performs as a typical current collector and distributes gas through a plurality of arches with heights suitable for providing a good reactant area [1]. Liu et al. [2,3] studied the effect of the interconnect rib contact resistance and flow characteristics on the performance of planar solid oxide fuel cell stack. The sensitivity test for the contact resistance in the aspect of the anode and cathode optimal rib sizes was conducted by Kong et al. [4].

Interconnects may be formed either from ceramics or from metal or alloy materials. Ceramic interconnects are normally used at temperatures between 800 and 1000 °C, whereas metallic interconnects are preferred at 750 °C or below. Although ceramic interconnects perform better than metal interconnects over long periods of use (ceramic is less susceptible to oxidation), ceramics have the disadvantages of being expensive and difficult to manufacture. Additionally, ceramics provide a low electrical conductivity compared to metal. Nickel- and steel-based alloys are promising interconnect materials for use in low-temperature (~750 °C) SOFCs. Their advantages over metallic interconnects include an

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* *Corresponding author*. Tel.: +82 42 350 3027; fax: +82 42 350 5027.
E-mail address: hjsung@kaist.ac.kr (H.J. Sung).

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extremely high electrical conductivity, a high thermal conductivity, and an enhanced durability for accommodating thermal stresses. The thermal expansion coefficient of a metallic interconnect must match those of the other cell components to avoid the generation of stresses under operating conditions [5,6].

A refined shielded slot may be used to substitute for the metallic interconnect. The shielded slot structure must satisfy three requirements: 1) provide fuel gases; 2) maintain the electrical contacts; 3) resist the compression load. The flow characteristics of shielded slots have been studied extensively; however, few studies have examined the performance properties of SOFCs prepared with shielded slots. Most application-based studies of shielded slots have focused on molten carbonate fuel cells (MCFC). Kim et al. [7] studied the channel patterns in an MCFC with an indirect internal steam reformer in which sheared protrusion structures were used in the current collector. The system was constructed to reduce the costs associated with heat control. Marra et al. [8,9] developed a computational model for a three-dimensional (3-D) periodic shielded slot module to identify the characteristic fluid–dynamics parameters. Kim et al. [10] simulated a channel with shielded slots that acted as a porous medium for achieving equivalent flow and heat transfer. Kim et al. [11] studied the relationship between the gas flow direction in an electrode and the performance characteristics of the MCFC. As mentioned earlier, most previous studies have examined the use of shielded slots in MCFCs; however, no applications to SOFCs have yet been described.

Three-dimensional analysis models are necessary for testing the performances of fuel cells designed with complex shielded slots. An analysis model of an SOFC was introduced by Achenbach [12]. Costamagna [13,14] included fuel gas diffusion in a micromodel of electrodes as a means for achieving a concentration overpotential. Chan and Xia [15] developed a microscale model of an anode to study the relationship between the electrochemical reaction and the gas transport properties. Chan et al. [16] developed a macroscale model of the electrochemical reactions that occur in SOFCs. The macroscale analysis model was coupled with a microscale model for estimating the electrode properties. Nam and Jeon [17] developed a comprehensive model, including a random packing sphere model, to model the electrochemical reactions and gas transport in the SOFC porous electrode. Hussain et al. [18] developed a mathematical model that included an electrode within both the backing and reaction layers. Recently, Choi et al. [19] examined the cell performance of a flat tubular SOFC under a range of functional layer conditions. They suggested appropriate values for the particle diameters and layer thicknesses using a microelectrode model.

The objective of this study was to explore the effects of a shielded slot on the performance of a planar SOFC. The 3-D electrochemical reaction model, including a microelectrode model, was used to test the cell performance. An optimal arrangement of shielded slots was proposed by testing the performances of the I–V characteristics, overpotentials, and contact resistance. Prior to analyzing the complex arrangement of shielded slots, simulations of various interconnect arrangements were conducted to understand the flow characteristics of the gas supply and electrical contact. The effects of various pattern arrangements and rib widths on the cell performances were examined. The gas supply area and electrical contact area determined the local cell performance. Thus, an arrangement pattern with an appropriate rib width was predicted to enhance the cell performance, given the complex arrangement of shielded slots.

Numerical simulations

Electrode modeling

In a porous composite electrode, electrochemical reactions occur at the triple phase boundary at which the electronic, ionic, and gas phases coexist. Detailed electrode micromodeling is required to predict the performances of planar SOFCs. The electrochemical reactions of the cells depend on the microstructural properties of the cell structure. The microstructural effects were included in the model by defining the active surface area per unit volume using a binary random packing sphere model in combination with percolation theory [14],

$$A_S = \pi(r_{\text{ion}} \sin\theta)^2 N_t n_{\text{el}} Z_{\text{el-ion}} P_{\text{el}} P_{\text{ion}}, \tag{1}$$

where r_{ion} is the radius of the ion-conducting particle and θ is the contact angle between the electron- and ion-conducting particles, assumed to be 15° [20]. Here, N_t is the total number of particles per unit volume that contribute to the percolation of the electron and ion particles [14,15],

$$N_t = \frac{1-\varepsilon}{4/3\pi r_{\text{ion}}^3\left[n_{\text{el}} + (1-n_{\text{el}})(r_{\text{ion}}/r_{\text{el}})^3\right]}, \tag{2}$$

where P_{el} and P_{ion} are the percolation probabilities of the electrons and ions, respectively. The percolation probability is the probability that a particle belongs to a percolating cluster that is connected at both ends to a source and sink [21,22]. In the porous electrode, the value of the electrical conductivity, which is needed to solve the charge conservation equation, could be estimated based on a corrected intrinsic electric conductivity value [17].

The internal structure of the cell included an anode support, anode interlayer, electrolyte, cathode interlayer, and cathode current collector. The fuel gas diffused through the electrodes to the triple phase boundary, at which position the electrochemical reaction occurred. The permeability of the porous electrodes was estimated using the correlation given by Jeong et al., which relates to the particle diameter d_p and the porosity ε [23],

$$\frac{K}{d_p^2} = \exp\left[0.709\ln\left\{\varepsilon^{11/3}\Big/(1-\varepsilon)^2\right\} - 5.09\right]. \tag{3}$$

Diffusion provided the main transport mechanism of the fuel gas through the electrode pores. This process could be described as ordinary diffusion or Knudsen diffusion, either of which mechanisms can occur in most SOFCs. Ordinary diffusion was dominant when the average pore size of the electrode exceeded the mean-free path of the fuel gas