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Short Communication

A study of short stack with large area solid oxide fuel cells by aqueous tape casting

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ABSTRACT

Solid oxide fuel cells (SOFC) are very attractive for their high energy conversion efficiency and pollution-free characters. A 10 cm * 10 cm fuel electrode-supported solid oxide cell with NiO/$Zr_{0.92}Y_{0.08}O_{2-\delta}$ fuel electrode, $Zr_{0.92}Y_{0.08}O_{2-\delta}$ electrolyte and $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3+\delta}$ air electrode has been used, which is fabricated by aqueous-based tape casting in conjunction with co-sintering. In this article, a short stack test structure of large area single cell has been designed and shown, and the maximum power density is 265.8 mW cm^{-2} at 800 °C with humidified H_2 as the fuel and air as the oxidant.

Introduction

Energy has always been a topic of concern and affected human's daily life [1,2]. How to use energy efficiently and reduce the environmental pollution caused by energy consumption are becoming more and more important. Solid oxide fuel cells (SOFC) are one of the most efficient devices for the electrochemical conversion of chemical energy into electricity, and have been gaining increasing attention in recent years for clean and efficient distributed power generation [3,4]. As SOFC operating temperature is from 600 °C to 900 °C, the wasted heat can be used to promote gas turbine or steam turbine to generate power, which causes the conversion efficiency of SOFC is the highest in Fuel Cell [5,6]. Due to the high operating temperature, the usage of fuel is very wide [7]. Hence, the primary goal in this field now is to reduce the capital cost of the SOFC-base power systems to effectively compete with other power generation technologies [8].

For the solid state structure, the design is very flexible, but it is mainly concentrated on the planar and the tubular structure [9–13]. Compared with the tubular SOFC, the planar

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SOFC has the advantage of simple process and high volume power density [14]. This type of SOFC is formed by a series of plane parallel connection of different functional layers. Those functional layers and their interface should keep many properties stable, in order to make SOFC operating with long stability. For example, the anode supported layer should have enough three phases interface to guarantee the electrochemical reaction to reduce the polarization over potential. At the same time, the anode supported layer should have enough mechanical strength and thermal expansion matching. The electrolyte should dense enough to ensure that the fuel gas and oxygen are blocked. Moreover, it should be thin enough to reduce the ohmic resistance. So the each layer and interface in SOFC is critically important.

Organic-based Tape casting is a more popular shaping technology in SOFCs manufacturing in the past for its low cost and easy process [15,16]. However, organic-based tape casting often involves the use of toxic solvents and hazardous additives, which is harmful to human health and the environment. For this reason, there are increasingly more attentions paid to development of aqueous-based tape casting.

Although there are some papers about planar solid oxide fuel cell fabricated by aqueous tape casting, most of them focus on studying button cells cut from large area cell [17]. The large area cells are very different from button cells in testing methods and conditions, and they can be used for setting up the short stack which is near to the practical applications. At the same time, many problems of large area cells have not been resolved [9,10,18,19], for example, the defects of thin electrolyte, the mechanical strength of single cell, the sealing [20–22], the gas flow field [23,24], the temperature field [25], the connector [26], and etc. Therefore, the characterization and testing of large cells is very necessary. The purpose of this article is to describe a testing method of large area single cell in research, and it is the further research on the previous work about large area solid oxide fuel cells by aqueous tape casting [27].

Experimental

Materials and fabrication procedure

The $Zr_{0.92}Y_{0.08}O_{2-\delta}$ (YSZ, TOSOH, Japan) powder was used to prepare the electrolyte layer, while commercial NiO (J. T. Baker, US) and YSZ were used for preparing fuel electrode layer. The $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3+\delta}$ (LSCF, Fuel Cell Materials, US) had been used as air electrode. The structure of the fuel electrode supported solid oxide fuel cell was Ni-YSZ/YSZ/LSCF. The large area single cell was fabricated by aqueous co-tape casting fuel electrode and electrolyte layers in conjunction with co-sintering process. After sintering, the half-cell was cut to 10 cm * 10 cm by laser cutting machine. The air electrode layer was screen printed on electrolyte surface with LSCF. The details of fabrication was shown in the previous paper [27].

Measurements

The Schematic diagram of SOFC stack structure was shown in Fig. 1. The Nickel foam and Ag gauze (WINTEK TECHNOLOGY PTE LTD) were current collectors in fuel electrode side and air electrode side respectively. The Mica sealing gasket (Fuel Cell Materials, US) was used as sealant. And the croffer 22 APU was used as the top/bottom interconnecting plate and the connector. Among all of the components above, design and arrangement of interconnects and sealing are very crucial to ensure proper supply of fuel and air through the designated gas flow channels. The single cell's area was 10 cm * 10 cm, and the effective area of the cathode was 8.9 cm * 8.9 cm. The short stack was heated to 850 °C and given some pressure to completely sealing, then it was cooled down to 800 °C with 2 °C min^{-1}. The cell electrochemical performance and impedance spectroscopy were obtained using an Autolab PG30/FRA system (Eco Chimie, Netherlands) at 800 °C with humidified H_2 as the fuel and air as the oxidant in the frequent range of 0.1 Hz–100 KHz with an excitation potential of 10 mV. The flow rate of the humidified hydrogen was 0.3 L min^{-1} on reducing the fuel electrode and 1 L min^{-1} during the testing. The flow rate of air was 0.75 L min^{-1} before the testing and 2.5 L min^{-1} during the testing. The four-probe configuration was used in the electrochemical testing. The microstructure of the fuel cell after the testing was analysed by using a scanning electron microscope (SEM, JEOL 5600, Japan).

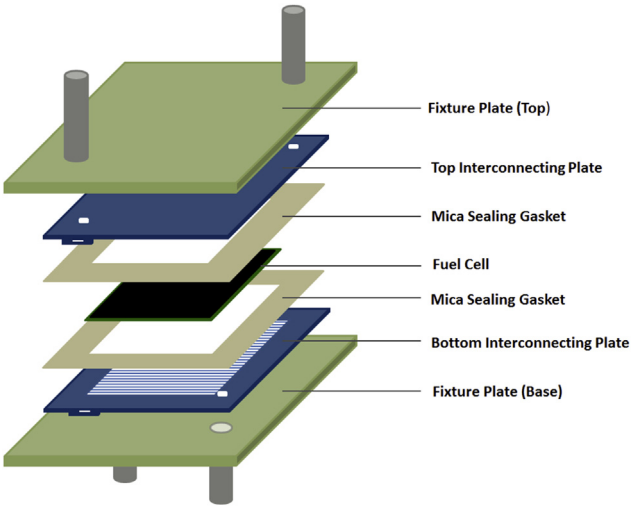

Fig. 1 – Schematic diagram of SOFC stack structure.

Results and discussion

Fig. 2 presents the microstructure of the cross-section of the large area fuel electrode-supported single cell after testing. The multilayer green tape was co-sintered at 1400 °C. Fig. 2(a) is the full view, and Fig. 2(b)–(d) are electrolyte, fuel electrode and air electrode, respectively. From these figures, the great structures were achieved, the dense enough electrolyte and the porous enough fuel electrode. The thickness of the whole cell is about 0.53 mm, and the electrolyte and the air electrode are 6.75 and 26.8 μm thick, respectively.

Fig. 3(a) shows the current–voltage (I–V) and current–power density (I–P) curves for short stack tested at 800 °C. The open circuit voltage (OCV) values are near 1.06 V, which are close to the theoretical values calculated

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