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Effect of stack configurations on single chamber solid oxide fuel cell, anode–cathode, anode–anode, and cathode–cathode configuration

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ABSTRACT

Two-cell solid oxide fuel cell (SOFC) short stacks with anode-facing-cathode (A–C), anode-facing-anode (A–A), and cathode-facing-cathode (C–C) configurations were fabricated and operated in single chamber conditions. Fuel cells consist of NiO/Y_2O_3-stabilized ZrO_2 (YSZ) anode support, YSZ electrolyte, and (La, Sr)MnO_3 (LSM) cathode. The A–C stack obtains the highest OCV, the A–A stack obtains the highest actual temperature of stack, and the C–C stack obtains the highest power output in the same condition. A high flow rate was necessary for the A–A stack to obtain a good performance of stack due to the non-selectivity anode. A low N_2 flow rate was propitious to the C–C stack; the peak power output was about 740 mW at N_2 flow rate of 100 cm^3 min^{-1}.

1. Introduction

As compared with conventional solid oxide fuel cells (SOFCs), single-chamber SOFCs (SC-SOFCs) usually operate in a diluted gas mixture of fuel and oxidant. This typical characteristic enables an SC-SOFC to have the advantages of being sealant-free and having rapid start-up and improved thermal and mechanical shock resistance [1]. The need for new portable equipment which is capable of providing higher energy density and specific energy makes SC-SOFCs stack attract a great deal of attention [2].

The operation mechanism of SC-SOFC is based on the selectivity of electrodes to the electrochemical oxidation of the fuel and reduction of the oxidant. The operating parameters including working temperature, flow rate, fuel-to-oxygen ratio, and flow geometry etc., have been investigated in many literatures [3–9]. Moreover, not only the electrolyte-supported but also anode-supported stacks consisting of several cells have been fabricated and operated successfully in single-chamber conditions [10–20]. Some designs of SC-SOFCs stack have been presented, and good results have been obtained with them. Shao et al. [14] fabricated a thermally self-sustained micro-stack that generated an open-circuit voltage (OCV) of 1.44 V and a maximum power output of about 350 mW. In our previous work, star-shape, cell-array and annular micro-stacks have been fabricated and operated successfully in CH_4–O_2–N_2 mixtures [15–18]. Hibino and co-workers [19,20] have operated an SC-SOFC stack in engine exhaust with a high power output of 1 W (12 cells, 12 cm × 5 cm).

Usually, there are three major configurations of an anode-supported stack in single chamber conditions i.e. the anode-facing-cathode (A–C), anode-facing-anode (A–A), and cathode-facing-cathode (C–C) configurations. The A–C configuration is commonly used in the assembly of SC-SOFC stack. The connection between series-wound cells is very simple in the A–C configuration stack. However, the effect of the distance on the electrodes especially on the cathode facing the distance between the two cells appeared in the A–C stack [16,18] .The A–A configuration is beneficial to increase the temperature of stack due to the heat from the exothermic reactions of the anode [21]. The thermally self-sustained micro-stack fabricated by Shao et al. [14] is an A-A configuration stack. The contribution of the A-A configuration toward the successful operation of their stack should not be neglected. If a stack consists of more than two cells, the configuration of this stack should combine the A–A and C–C configurations. In other words, both the A–A and C–C configuration are important to the assembly of the stack. However, so far the C–C configuration stack in single chamber condition had no report. In this study, the A–C, A–A, and C–C stacks with the same cell distance were fabricated and operated in CH_4–O_2–N_2 mixtures. The performances of stacks and the cells in stacks have also been investigated.

2. Experimental

Anode-supported YSZ membrane fuel cells were supplied by Ningbo Institute of Material Technology and Engineering, Chinese

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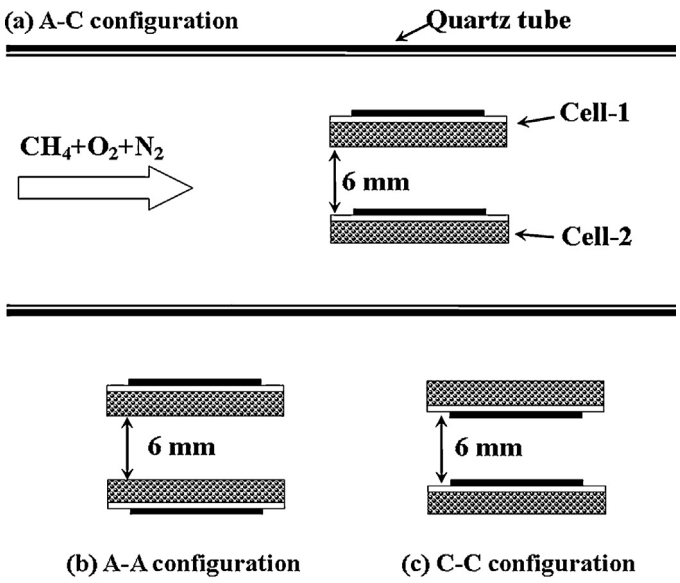

Fig. 1. The schematic diagrams of the dual-cell micro-stacks, (a) A–C configuration, (b) A–A configuration, and (c) C–C configuration.

Academy of Sciences. Anode, electrolyte and cathode are NiO–YSZ, YSZ and (La, Sr)MnO_3 (LSM), respectively. The size of the fuel cell is 2.0 cm × 1.0 cm. The LSM cathode active area is 1.5 cm^2. The anode substrates were reduced in hydrogen at 700 °C before assembly. The electrode surfaces were covered with a thin layer of Ag paste (DAD-87) as the current collector. The two cells were connected by silver wires, and then they were connected to the test instruments with silver wires.

Fig. 1 shows the schematic diagram of the dual-cell micro-stacks in single chamber. The A–C configuration stack in single chamber is shown in Fig. 1a. The A–A and C–C configuration stacks are shown in Fig. 1b and c, respectively. The fuel cells were assembled in a piece of lightweight dichroite ceramic board with many square holes. In order to fix the cells in place, the surface of the ceramic board was fluted. The two cells were in series and the distance is 6 mm for all stacks. The performance of the stacks and the cells were tested in a quartz tube (inner and outer diameters of ~21.6 mm and 24.6 mm, respectively). The gas mixture consisted of methane, oxygen and nitrogen as inert diluting gas. The flow rate of these gases and the ratio of methane to oxygen were controlled by the mass-flow controllers (MFCs, D08-4D/2M, Seven-Star Huachuang, China). The performances of the stacks and the cells were measured by Ivium electrochemical analyzer.

3. Results and discussion

3.1. The anode-facing-cathode (A–C) stack

The anode-facing-cathode (A–C) configuration is commonly used in the assembly of SC-SOFC stack due to the simple connection between the series-wound cells. And that the performance of the stack and the effect of the cell distance on the electrodes facing the distance have been reported in previous studies [16–18]. In order to compare with other configurations, some results of the A–C configuration stack still were presented in this paper.

Fig. 2 shows the *I–V* and *I–P* curves of the A–C configuration stack and the cells at CH_4/O_2 = 1 and 700 °C. The total flow rate of CH_4 and O_2 is 280 cm^3 min^{-1} and the flow rate of N_2 is 200 cm^3 min^{-1}. The OCV of the stack is 1.80 V, and the maximum power output is 566 mW at CH_4/O_2 = 1. The performance of Cell-1 is much higher than that of Cell-2 due to the effect of the distance on the cathode

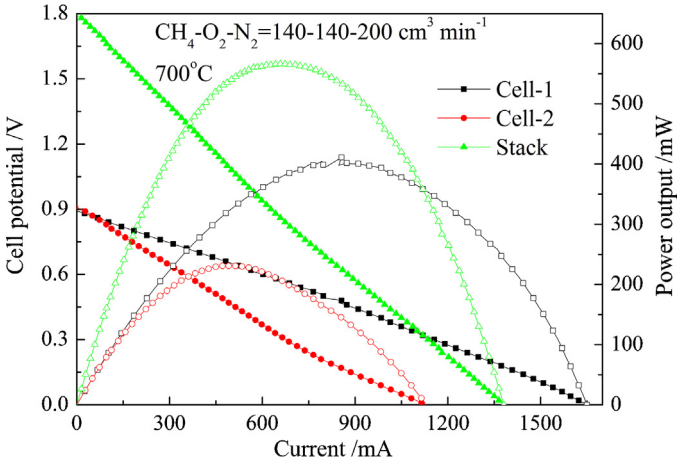

Fig. 2. *I–V* and *I–P* curves of the A–C configuration stack and the cells at CH_4/O_2 = 1, and 700 °C (CH_4–O_2–N_2 = 140–140–200 cm^3 min^{-1}).

of Cell-2 [18]. Additionally, not only the cathode (Fig. 2) but also the anode facing the inner of the stack is influenced by the distance. The performance of Cell-1 is lower than that of Cell-2 due to the effect of the distance when the CH_4 flow rate is less than 80 cm^3 min^{-1} at 750 °C as shown in Fig. 3. The two cells have the same power output at CH_4 flow rate of 80 cm^3 min^{-1} in Fig. 3.

3.2. The anode-facing-anode (A–A) stack

The A–A configuration stack would not appear the mutual effect between the two symmetrical cells and it is beneficial to increase the stack temperature by the exothermic reactions in anode. The test of the A–A stack was similar to the A–C stack, so the flow rate of N_2 was fixed at 200 cm^3 min^{-1} at the beginning of the experiment. However, the results of the A–A stack were not the same as the expectant ones. The OCV of the A–A dual-cell stack is only 0.96 V and the peak power output is 87 mW at 650 °C. So the effect of N_2 flow rate on the performance of stack was investigated firstly. Table 1 shows the performance of the A–A stack for various N_2 flow rates at 650 °C when the ratio is fixed at CH_4/O_2 = 1. Both the OCV and the maximum power output are increase with flow rate of N_2. We know that the anode probably consumed more gases than the cathode from the results of the A–C stack. And that the

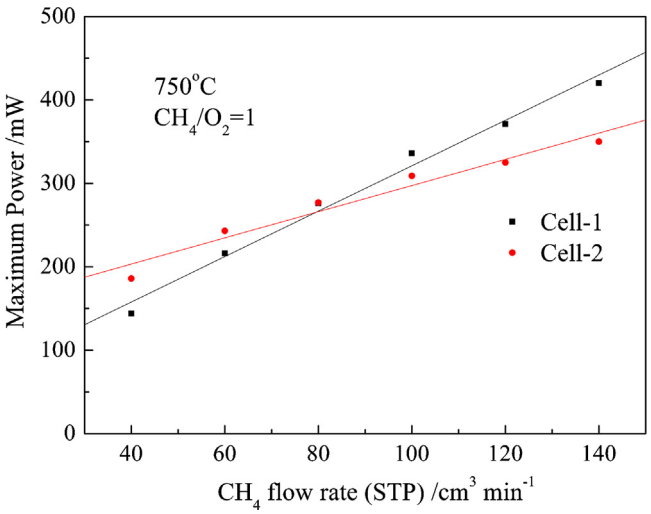

Fig. 3. The maximum power outputs of the cells in the A–C configuration stack at CH_4/O_2 = 1 and 750 °C (N_2 = 200 cm^3 min^{-1}).