OPERATION OF MICRO-SOFC BY AN INTERNAL MICRO HEATER

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Abstract: We first demonstrated the operation of micro-SOFCs with an internal micro heater. The heater was made from a sputtered Pt thin film during fabrication processes of micro-SOFCs, and surrounded each cell. It heated the inside of the heater to approximately 300 ^oC within three minutes without any fracture. The cell showed an open circuit voltage (OCV) of 0.5 V and a maximum power density was 145 $\mu W/cm^2$. From the results, we confirmed the effectiveness of the operation by an internal micro heater especially on the viewpoint of start-up time.

Keywords: micro-SOFC, self start-up, internal micro heater

INTRODUCTION

Micro solid oxide fuel cells (Micro-SOFCs) are promising candidates for power sources of mobile electronic devices such as laptop personal computers and smart-phones, which require high power and longtime operation. Micro-SOFCs show superiorities to other alternatives. In particular, an energy density of liquid fuel for micro-SOFCs is significantly higher than other alternatives such as Li-ion batteries and energy harvesting systems. Micro-SOFCs also have advantages to micro fuel cells based on polymer electrolytes on the viewpoint of mechanical stability. Micro-SOFCs, therefore, have attracted many researchers [1-5]. Recently, power densities of more than 100 mW/cm^{-2} at temperatures above 400 ^oC have been achieved. This value is quite promising for the power sources. We have also been developing micro-SOFCs with the object of operating at 300^oC [6]. It shows a maximum power density of 2.8 mW/cm^2 at 300^oC, and suggests that the operation at 300 ^oC is possible.

However, there are some obstacles such as packaging, thermal management, and, self start-up, to be overcome for practical application. Because micro-SOFCs operate at the temperature range of 300 ^oC to 500 ^oC, it is necessary to heat them to operating temperature for start-up without any kind of support. In the case of SOFCs for domestic usage, combustion heat of fuel gases, *i.e.*, natural gas, is used for start-up with the support of the grid electricity. Hence, systems, which make micro-SOFCs self start-up, do not established. In the filed of micro-SOFCs, some concepts for self start-up although have been discussed, those are not proved experimentally and theoretically.

In this study, we, therefore, focused on this problem. We experimentally tested one concept, in which micro-SOFCs are heated by an internal micro heater using stored electricity. We fabricated micro-SOFCs with an internal micro heater made from Pt thin films, and performed power generation test using the internal micro heater. Based on the results, we discussed about the effectiveness of this concept for practical application of micro-SOFCs.

EXPERIMENTAL

Micro-SOFCs were fabricated using conventional MEMS techniques. The schematic illustration of the micro-SOFCs is shown in Fig.1. The figure shows the design of one cell and at least 16 cells were fabricated on a same silicon substrate. Because a gas flow channel was fabricated by wet etching using tetramethylammonium hydroxide (TMAH) as an etchant, the gas flow channel showed trapezoid cross section. A thin film electrolyte (t = 600nm) was yttrium-doped barium zirconate (BZY), and an anode and a cathode (t = 300nm) were porous Pt-Pd (8:2). A heating element of an internal micro heater was Pt (t = 200nm). The micro heater surrounded and heated an opening, in which power generation was performed, from outside. The heating element was covered with a SiO_2 layer to electrically separate micro heater and the cathode.

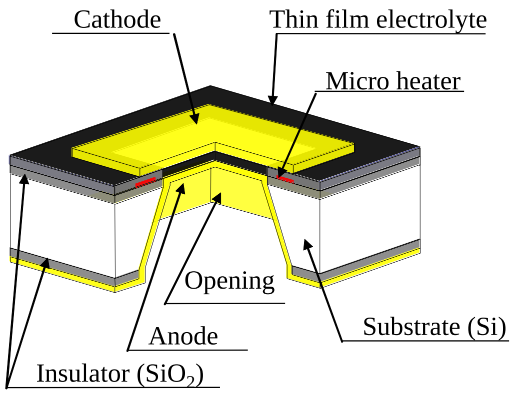

Figure 1 Schematic illustration of the micro-solid oxide fuel cell design with an internal micro heater.

Detailed fabrication processes are shown in Fig.2. The micro heater was sputtered on the surface of the silicon substrate with SiO_2 insulation layers using a stencil mask. The sputtered Micro heater was covered with the SiO_2 insulation layer, and the insulation layer was partially removed by wet etching using buffered hydrofluoric acid (BHF) as an etchant to make contact pads of the micro heater and the opening. The BZY electrolyte layer was deposited by conventional pulsed laser deposition (PLD) method with fourth harmonic Nd: YAG laser (λ= 266nm). The laser power was 40 mJ at a frequency of 5 Hz. During deposition, the substrates were maintained at 900 °C under oxygen partial pressure of about 10 Pa. After deposition, the silicon substrate was removed to create a fuel channel by TMAH wet etching and xenon difluoride (XeF_2) dry etching. Finally, the porous Pt–Pd electrodes were deposited by dc sputtering. The yield of each cell using these fabrication processes was approximately 100%.

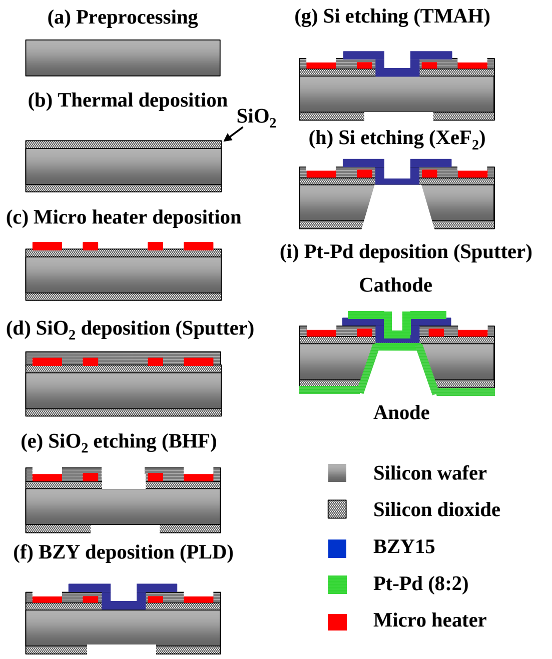

Figure 2 Diagrams of the fabrication process of the micro-SOFCs. BHF: Buffered hydrofluoric acid; TMAH : Tetramethylammonium hydroxide

Wire probes were connected to the contact pads, and dc electricity was supplied to the internal micro heater by a DC power source. By supplying dc electricity, Joule heat was generated at the heating element, and the micro-SOFC, which was surrounded by the heating element, was locally heated to operational temperature.

Power generation test was performed in the locally heated micro-SOFC. Detailed apparatus in the power generation test is shown in Fig.3. But in this study, a heater in Fig.3, which heated whole micro-SOFCs, was not used A wet hydrogen atmosphere was maintained around the anode by mass flow controllers and a water bubbler. The water vapor partial pressure was 3.3 kPa (25 °C). The cathode atmosphere was laboratory air at 25 °C.

The apparatus in power generation test only had one thermo couple to measure temperature in whole micro-SOFCs. It was not able to measure temperature in the locally heated micro-SOFC. Hence, we estimated operational temperature from cell resistance calculated from I-V characteristics in power generation test.

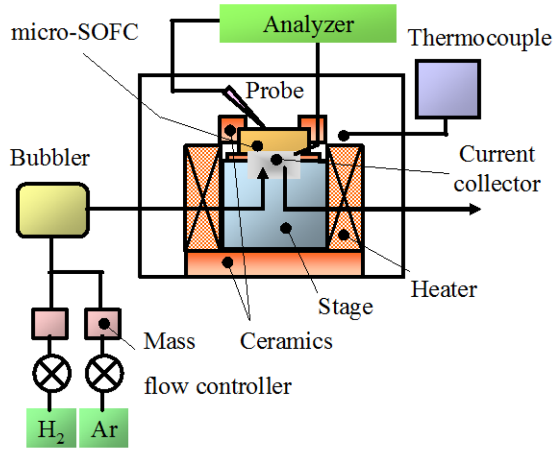

Figure 3 Schematic illustration of the testing apparatus.

RESULTS AND DISCUSSION

Figure 4 shows optical images of the micro SOFC with the internal micro heater. As shown in Fig.4 (a), the heating element is 50µm width and surrounded the opening. Total length of the heating element was designed to be 1000µm. Measured total resistance of the internal micro heater is 21.2Ω. As shown in Fig.4 (b), although the heating element is electrically separately from the cathode, the heating element is very close to the cathode, and it was able to only heat inside micro-SOFC.

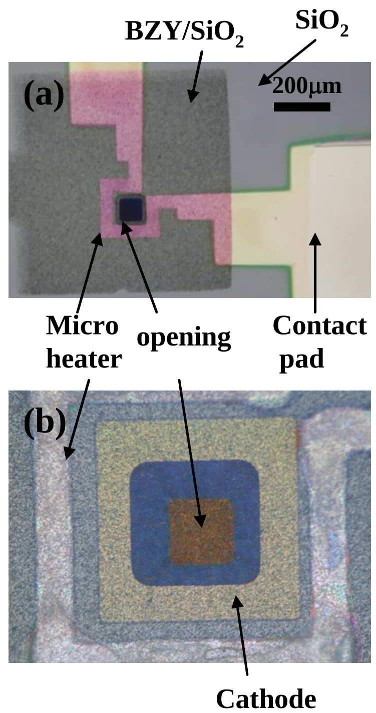

Figure 4 Optical images of the micro-SOFC with the internal micro heater. (a) : Overview from cathode side. (b) : Close-up

Figure 5 shows an image observed using an infrared camera in power generation test. In the power generation test, dc electricity only supplied to one internal micro heater on one Si substrate. Locally heated micro-SOFC is appeared as bright square in Fig.5. Considering color distribution around the locally heated micro-SOFC, the heating element confirmed to heat not only the inside micro-SOFC but also outside. However, it was also confirmed that outside temperature was not so high and the distribution was limited to be several mm.

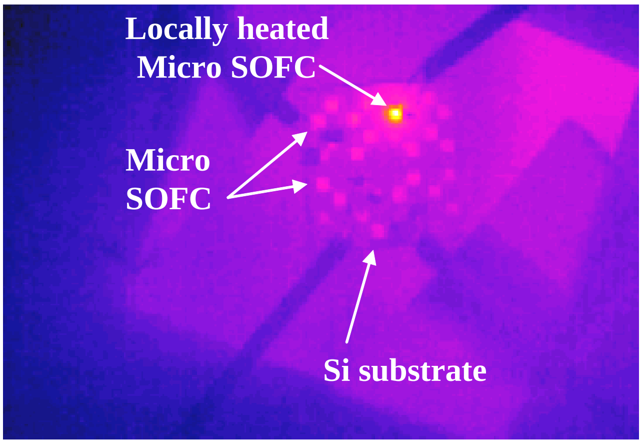

Figure 5 Image of an infrared camera in the power generation test.

In the power generation test, at first, an anode atmosphere was wet Ar at room temperature. The electricity, which supplied to an internal micro heater, increased to 0.17W for three minutes step-by-step. Then, the anode atmosphere was changed to wet hydrogen. After 10 minutes, OCV of 0.5 V was observed. Observed I-V and I-W characteristics were shown in Fig. 6. Area specific resistance of the micro-SOFC is calculated to be about 500 Ω/cm^2. In accordance with our results in micro-SOFCs without the internal micro heater, such area specific resistance was obtained at 300 °C. Hence, the temperature of the opening, which was heated by the internal micro heater, was estimated to be 300 °C.

The micro-SOFC showed the maximum power density of 145 $\mu W/cm^2$. However, OCV is significantly lower that theoretical open circuit voltage of about 1.1 V. During the test, any fracture was not observed in the opening. In addition, OCV of 1.0V at 300°C was obtained in micro-SOFCs without the internal micro heater. Hence, it is speculated that a mechanical gas leakage from other micro-SOFCs on the same silicon substrate or the rim of the Si substrate was due to low OCV.

In this study, we performed the power generation test in the micro-SOFC with the internal micro heater. The electrical power was successfully generated in the test by supplying electricity of 0.17 W. Hence, it is confirmed that local heating by the internal micro heater using stored electricity is able to be used for self start-up. In addition, the electricity was generated within 13 minutes without any fracture. In our previous study, micro-SOFCs, which were heated by an external heater, were fractured, if the micro-SOFCs were heated rapidly. Therefore, it took an hour for start-up. This study indicates that the internal micro heater and self start-up by it can reduce the duration of self start-up significantly. Such rapid self start-up is an essential feature of the power sources for mobile electronic devices. In this study, because electricity was supplied to the internal micro heater step-by-step to prevent fracture, it took three minutes to be heated to 300°C. In addition, because the initial anode atmosphere was Ar, ten minutes was spent for gas exchange. Hence, the improvement of processes in power generation test can reduce the self start-up time shorter than that in this study.

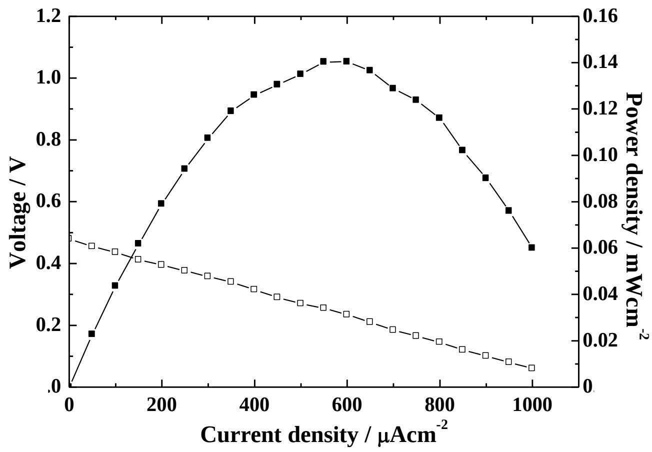

Figure 6 I-V and I-W characteristics of the micro-SOFC with the internal micro heater.

CONCLUSION

We fabricated the micro-SOFCs with the internal micro heater made of Pt, and performed the power generation test by heating the micro-SOFC using the internal micro heater. We were able to generate electrical power by locally heating within 13 minutes. The duration was significantly shorter than that in micro-SOFCs operated by an external heater. Hence, it is confirmed that the internal micro heater and self start-up using it is effective concept for the power sources for mobile electronic devices.

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