

# Thermal management of power sources for mobile electronic devices based on micro-SOFC

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**Abstract.** Small power sources based on micro-SOFC for mobile electronic devices required two conditions, *i.e.*, thermally compatibility and thermally self-sustain, because of high operating temperature over 300 °C. Moreover, high energy efficiency was also required. It meant that this system should be designed considering thermal management. In this study, we developed micro-SOFC packages which have three functions, thermal insulation, thermal recovery, and self-heating. Heat conduction analysis based on finite element method, and thermochemical calculation revealed that vacuum thermal insulation was effective for size reduction and gas-liquid heat exchanger could reduce the temperature of outer surface. We fabricated the package with three functions for proof of concept and evaluated. As a result, it was suggested that developed package could satisfy both two requirements with high efficiency.

## 1. Introduction

Recently, high power and long usable power sources are strongly required as development of mobile electronic devices such as mobile phones and laptop computers. As new power sources, micro solid oxide fuel cells (micro-SOFCs) which utilize liquid fuels attract much attention for high power density [1]. Long operation is possible for micro-SOFCs by refueling and it is not restricted by battery charge. Hence, it is expected to be the power source of recent mobile electronic devices which consume a large amount of power. In previous, diverse types of micro-SOFCs [2, 3] and a maximum power density of 1 W/cm<sup>2</sup> at 500°C was reported [4].

As shown in the literature, high performance of micro-SOFCs was exhibited. However, they have many problems of durability and repeatability for practical use. Additionally, it is necessary to consider how to heat up micro-SOFC cells to operation temperature, compatibility with other electronic circuits and thermally self-sustained condition. We already solved the problem of heat up with internal micro-heater. In the system, power density of 0.14W/cm<sup>2</sup> at 300°C was achieved [5].

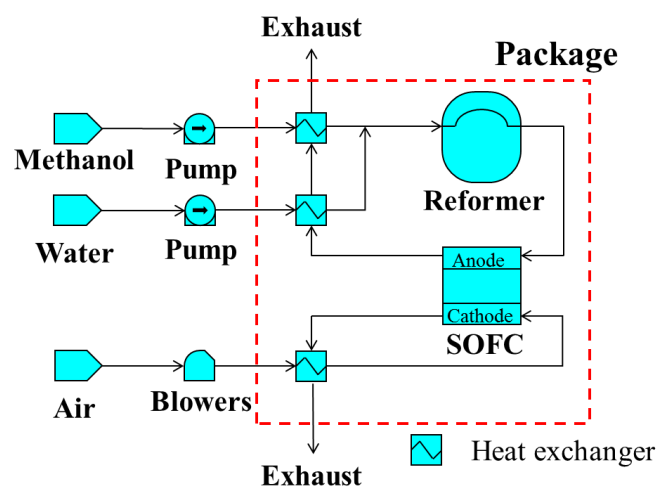
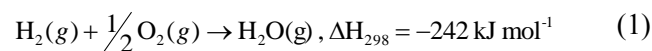
In this study, thermal design for micro-SOFC package was proposed in order to adopt the micro-SOFCs into a power source of compact mobile electric devices. We fabricated the micro-SOFC package with thermal insulation and experimentally confirmed the insulation performance.

## 2. Thermal design of micro-SOFC system

Applying micro-SOFC system as independent power sources, thermally self-sustained condition is required, *i.e.* micro-SOFC packages should keep operating temperature more than 300°C only by the generated heat during power generation. Micro-SOFC cells are heated up to operating temperature



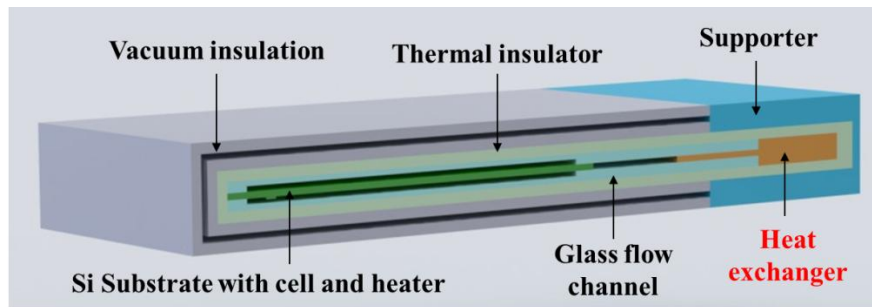
with internal micro heater using stored electricity and power generation is started. For the reaction of fuel cells as shown in Eq. (1), usable electric energy is produced from the difference of enthalpy in Eq. (1). Rest of the energy is released as heat which is usable to keep operating temperature. For thermally self-sustained condition, the amount of heat generated during power generation needs to exceed that of heat loss from surface of the package and heat transfer by exhaust gas. We calculated thermally self-sustained condition of a micro-SOFC system fueled by methanol and water that has reformer and heat exchanger from exhaust gas as shown in Fig.1. The result confirmed that heat loss with exhaust gas was dominated in this system. Hence, recovering the heat of exhaust gas with the gas-liquid heat exchanger was essential to achieve thermally self-sustained condition.



**Fig.1** Schematic illustration of micro-SOFC system. This system consists of micro SOFC cell, reformer and heat exchanger.

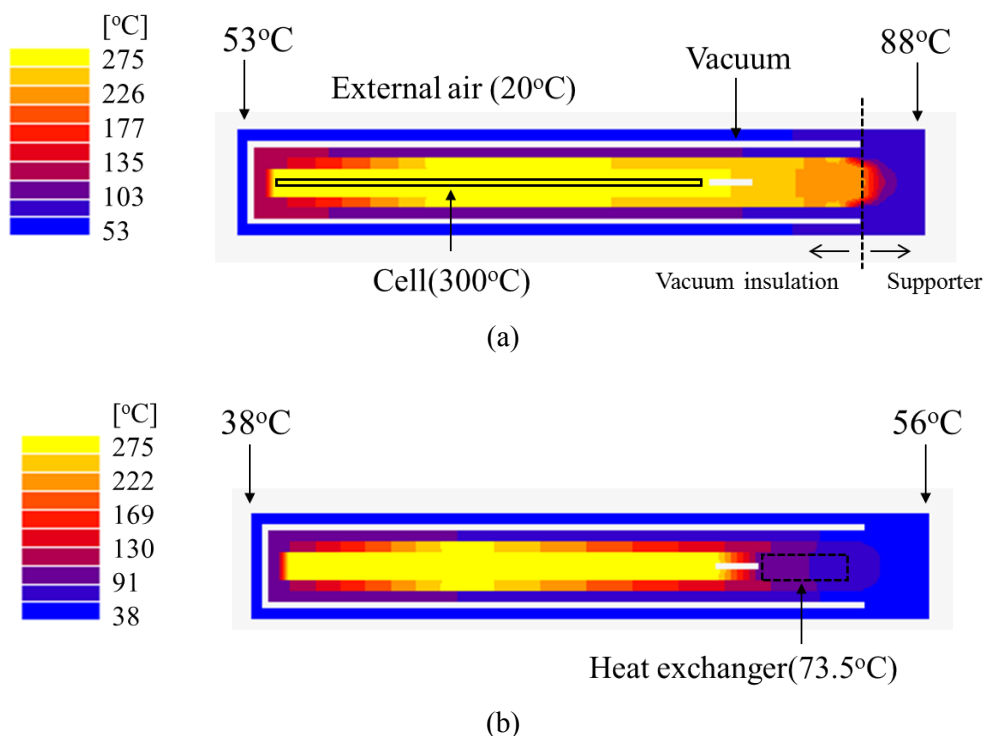
Micro-SOFC packages also require thermal insulation to keep the surface temperature below about 85°C, which is maximum operating temperature of other electronic circuits. However, the insulation structure size is restricted to contain micro-SOFC package in compact mobile electric device. We applied vacuum insulation for the package. Vacuum insulation technique is widely used for thermal insulation in MEMS devices such as gas sensors.

Proposed design of the micro-SOFC package with vacuum insulation and the heat exchanger was shown in Fig.2. Silicon substrate with SOFC cell and micro heater was contacted by glass flow channels. Glass flow channels were surrounded by thermal insulator such as glass fibers and, the vacuum insulator was set on the outside. Glass flow channels were connected to the heat exchanger filled with liquid fuels. The heat of the exhaust gas was recovered by the liquid fuel through heat exchanger.



**Fig.2** Designed micro-SOFC package with the vacuum insulator and the heat exchanger.

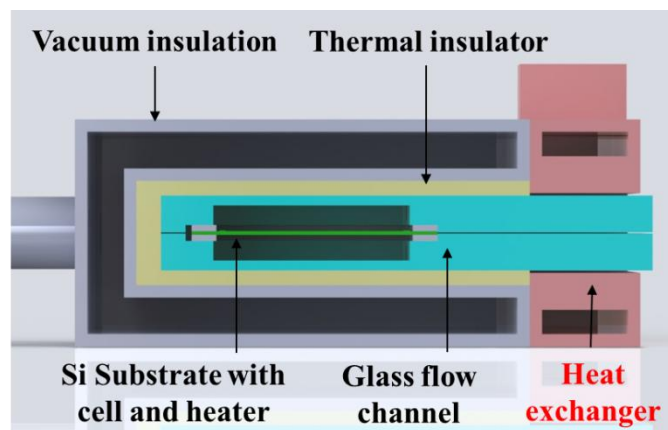
To estimate thermal insulation performance of the proposed micro-SOFC package, temperature distribution was calculated by the finite element method (MSC Marc 2010r2) as shown in Fig.3. Temperature of the cell is fixed 300°C and outer package was exposed external air (20°C). In the case of the package without heat exchanger, surface temperature of the package was kept from 53 to 88°C. It could meet the requirement when the cell temperature was 300°C by means of only vacuum insulation. In the case of the package with heat exchanger, surface temperature of the package was kept from 38 to 56°C. In this time, the heat exchanger was filled with 50 vol.% methanol, which boiling point was 73.5°C, as liquid fuel. As long as the liquid is evaporated, temperature of the heat exchanger is kept constant. Therefore, heat conduction from high temperature glass flow channels to vacuum insulator was prevented and low surface temperature was achieved. In accordance with the result, vacuum insulation could achieve low surface temperature as long as the cell temperature up to 300°C. Furthermore, the surface temperature can be reduced more with heat exchanger. Thus, the gas-liquid heat exchanger was effective for not only achieving thermally self-sustained condition but also reducing surface temperature of the package.



**Fig.3** Cross sectional temperature distribution of the package (a) without heat exchanger and (b) with heat exchanger

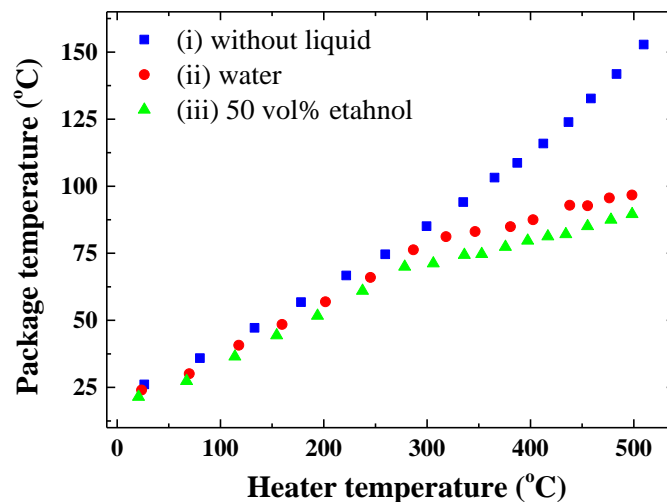
### 3. Cooling performance of the insulation package

We actually fabricated the micro-SOFC package, as shown in Fig. 4, to evaluate cooling performance of the insulation package. Considering the convenience for evaluation test and fabrication process, dimension of package was decided to 46 mm×38 mm×18.5 mm. The vacuum package and the heat-exchanger were made of stainless-steel. Silicon substrate with cells and micro-heater was fabricated in accordance with our previous result [5]. Glass flow channel was made of Tempax glass. Thermal insulator (YUTAKA CORPORATION, ceramic paper, 0.1 W/(mK)) was installed between glass flow channels and vacuum package to prevent heat conduction. The base pressure in a vacuum zone was maintained under 0.2 Pa. Silicon substrate was heated up to 500°C by internal micro heater fabricated on the cell. Surface temperature of the package was measured by thermocouple. Cooling performance was evaluated at three conditions; heat exchanger (i) without liquid, (ii) with water, and (iii) with 50 vol% ethanol solution.



**Fig.4** Cross sectional image of the fabricated micro-SOFC package

As shown in Fig. 5, micro heater was heated up to operating temperature of micro-SOFCs. In the case of (i), surface temperature became 152.8°C when micro heater temperature was 500°C. It was caused by heat conduction from glass part to surface of the package with the inside wall. In the case of (ii) and (iii), surface temperature was 96.7°C and 89.6°C, respectively, when micro heater temperature was 500°C. The heat exchanger was kept the boiling point of the liquid, i.e. 100°C for (ii), 89°C for (iii), as long as the liquid was evaporated. In accordance with the result, it was possible to keep surface temperature of the package sufficiently low with heat exchanger. Therefore, we can additionally reduce surface temperature using low boiling point liquid such as methanol because temperature of the heat exchanger depends on boiling point of the filled liquid. In consideration of the convenience for evaluation test and fabrication process, fabricated package became larger than the proposal design. However, it was considered that the cooling performance was not drastically changed because size of the vacuum zone was independent of the performance. Therefore, the vacuum package downsized to install into mobile electronics devices also keeps high insulation performance. Here we focused on the cooling performance of the heat exchanger to reduce surface temperature. In the future we will propose the micro SOFC package which can achieve thermally self-sustained condition and low surface temperature at the same time.



**Figure.4** Evaluated cooling performance at three conditions; heat exchanger (i)without liquid, (ii)with water, and (iii)with 50 vol% ethanol solution.

#### 4. Conclusion

We thermally designed the micro-SOFC package for applying micro-SOFCs to power source of mobile electronic devices. Thermally self-sustained condition is required for portable power source. Considering heat loss due to exhaust gas, recovering the heat of exhaust gas with the heat exchanger was adopted in the micro-SOFC system. We applied vacuum insulation for downsizing and the proposed package with vacuum insulation and heat exchanger. The proposed package could achieve thermally self-sustained condition and low surface temperature. We focused on cooling performance of the heat exchanger to reduce surface temperature and experimentally confirmed. As a result, surface temperature of the package was achieved below 90°C for electronic circuit. However the package has a problem with thermally self-sustained condition. We will continuously design the micro-SOFC package for compatibility with thermally self-sustained condition and low surface temperature.

#### Acknowledgements

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#### References

- [1] Evans A, Bieberle-Hutter A, Rupp J L M and Gauckler L J 2009 Review on microfabricated micro-solid oxide fuel cell membranes *Journal of Power Sources* 194 119-29
- [2] Kerman K, Lai B K and Ramanathan S 2011 Pt/Y<sub>0.16</sub>Zr<sub>0.84</sub>O<sub>1.92</sub>/Pt thin film solid oxide fuel cells: Electrode microstructure and stability considerations *Journal of Power Sources* 196 2608-14
- [3] Kerman K, Tallinen T, Ramanathan S and Mahadevan L 2013 Elastic configurations of self-supported oxide membranes for fuel cells *Journal of Power Sources* 222 359-66
- [4] Shim J H, Park J S, An J, Gur T M, Kang S and Prinz F B 2009 Intermediate-Temperature Ceramic Fuel Cells with Thin Film Yttrium-Doped Barium Zirconate Electrolytes *Chemistry of Materials* 21 3290-6
- [5] Iguchi F, Kubota K, Inagaki Y, Tanaka S, Sata N, Esashi M and Yugami H 2011 OPERATION OF MICRO-SOFC BY AN INTERNAL MICRO HEATER. *Proceedings of PowerMEMS2011* 411-414