

A NEW PLATFORM CONCEPT FOR MICRO-SCALE SOFC USING LOW TEMPERATURE CO-FIRED CERAMIC TECHNOLOGY

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Abstract: Micro-scale solid oxide fuel cells (μ -SOFCs) based on microfabrication processes have been found to be interesting as a battery replacement for portable power generation. The system consists of a fuel cell element, a fuel processing unit, a thermal control system and packaging for the electrical and fluidic connections as well as for mechanical support. The system is capable of operating above 500°C under both oxidizing and reducing atmospheres. Due to the relatively large size, complex fluidics and silicon microfabrication manufacturing is not practical for fabrication of the complete package and the gas processing unit (GPU). Low-temperature co-fired ceramic technology (LTCC) has recently emerged as an alternative solution to packaging μ -SOFC devices because of its easy 3D structuration capabilities allowing for integration of fluidics, combined with stable electrical connections, and outstanding thermal and chemical stability. In this paper, we propose a new concept of a packaging, GPU and test platform for μ -SOFC applications using LTCC technology. The platform primarily functions as a hotplate. Slender bridges carrying the electrical power supply and fluidic ports are used for thermal decoupling, allowing low conduction losses and convenient low-temperature interconnects, while providing mechanical support for the hot zone. Screen-printed thick-film silver palladium and platinum meanders are used as both heating elements (for testing and startup) and temperature measurement devices. The electrical characterization of the temperature regulation system was evaluated. The resistance-temperature behavior of the heating meanders was also characterized.

Keywords: LTCC, SOFC, temperature regulation, micro-electronics

INTRODUCTION

Innovative approaches to micro power generation have attracted a great deal of interest because of their important roles in developing portable electronic devices such as laptops, medical devices and multimedia players. As microfabrication technologies flourished, micro scale solid oxide fuel cells (μ -SOFC) have become a promising candidate in the field of micro power generation due to their potentially high generation efficiency [1-2]. Such μ -SOFC system consists of a fuel cell membrane, a fuel processing unit, a thermal regulation system and packaging for the electrical, fluidic connection and mechanical supports [3]. Although μ -SOFC technology is undergoing strong development, there are still several unsolved problems such as the thermal management, the micro scale fluidic integration and electrical interconnection at high temperature in both of oxidizing and reducing atmospheres. Low-temperature co-fired ceramic technology (LTCC) offers the possibility to unify the μ -SOFC system through its easy capability for 3D structuration, convenient electrical interconnection as well as the excellent thermal and chemical stability [4-8]. In this work, a hotplate test platform system for μ -SOFC applications is proposed and developed. The concept of the hotplate test platform system is described and the results of initial electrical characterization are discussed.

CONCEPT OF LTCC HOTPLATE TEST PLATFORM

LTCC hotplate module

The LTCC hotplate module in the testing platform was designed to provide heat for the μ -SOFC membrane. The LTCC hotplate module should be capable of decoupling the μ -SOFC operating temperature from its interconnections, so that regular electronic control modules and fluidic ports may be connected. A slender bridge structure on the LTCC hotplate can meet those requirements as shown in Fig. 1. The overall dimension of the LTCC hotplate module is 12 mm x 30 mm x 1 mm, with a 7 mm long central bridge and two side bridges. The hot zone area is 12 mm x 20 mm. The distance from the central axis of the hotplate module to the central axis of the side bridges is 5.3 mm.

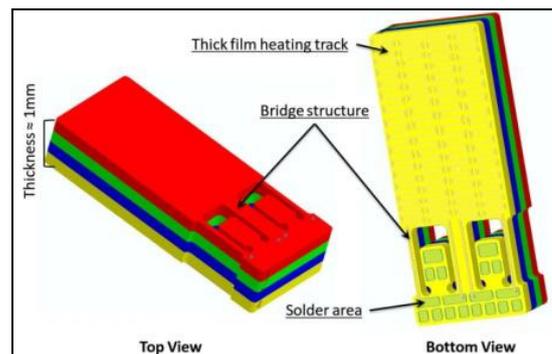


Fig. 1: Schematic of the LTCC hotplate module

At the operating temperature, due to the thermal expansion of LTCC materials, thermal stress develops at the side bridges. The half-length of the side bridges was considered as cantilever beams with an end load. Considering the temperature difference is 600°C, the maximum ensuing thermal stress is 109 MPa, which is smaller than the mechanical strength of LTCC materials (200 MPa).

Between the bridge structures on the hotplate module, a 2 mm wide open space separates the hot and cold zone of the LTCC hotplate. Considering the high-temperature thermal conductivity is ~ 0.05 W/K/m, the calculated thermal resistance of the air gap is about $5\text{'}300$ K/W. The thermal conductivity of LTCC materials is usually ~ 4 W/K/m, yielding a thermal resistance of 460 K/W for the bridge structure. Thus the bridge structure thermally decouples the hot zone efficiently.

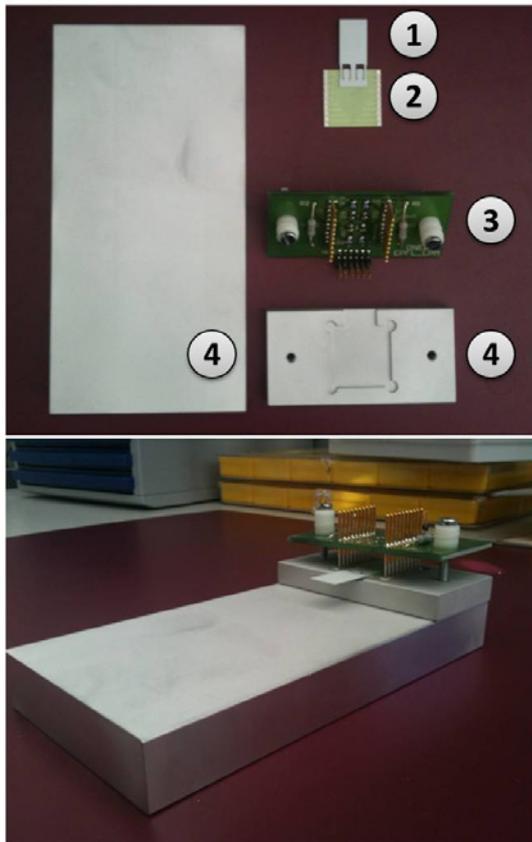


Fig. 2: The hotplate platform for μ -SOFC (1. LTCC hotplate module, 2. Ceramic interconnection, 3. Electronic control module, 4. Mechanical carrier)

The hotplate consisted of 4 layers of Heraeus HeraLock HL-2000 LTCC green tapes with a thickness of 133 μm , which were cut as bridge structure using an LS9000 laser (Laser Systems, Germany). The bottom layer was screen printed with silver palladium or platinum heating meander tracks [9] (~ 15 μm fired thickness). Then, the processed sheets of green tape were stacked, aligned and laminated at room temperature with a pressure of 20 MPa for 10 minutes. The laminated hotplate was fired in air using a standard LTCC firing profile, with a

20 min dwell at 875°C (Fig. 2). Platinum (Pt) and silver palladium (AgPd) are both positive temperature coefficient thermistor material. They could be used as self-heating temperature sensor for the LTCC hotplate to regulate the temperature of the LTCC hotplate. Platinum was an ideal heating element for the hotplate module because of its outstanding stability in various atmospheres and chemical stability at operation temperature of the μ -SOFC (500 – 600°C). To achieve a good thermal homogeneity, two separate heating tracks were placed.

Other supporting modules

To provide a stable mechanical basis, convenient electrical connections and an efficient pathway for heat dissipation, an alumina ceramic module (Fig. 2-2) with screen-printed conduction tracks was used as an electrical interconnection between the cold end of the LTCC hotplate module and the electronic control module (Fig. 2-3). The ceramic interconnection also carried the LTCC hotplate by attaching it with solder.

The electronic control module is designed to provide power on basis of the temperature information from the self-heating PTC heating tracks. The temperature is determined by the resistance of the heating tracks. To measure their resistance, on the module, the voltage of the heating tracks was measured by a 4-wire and voltage divider setup. A shunt resistor was connected to each heating track in series to measure its current. The resistance of the heating tracks was measured and based on their PTC temperature-resistance relationship, the temperature on the hotplate was obtained.

An aluminum mechanical carrier (Fig.2-4) was designed to carry the complete system and provide an efficient heatsink. The soldered hotplate-ceramic module can be easily placed onto the carrier. The spring contacts of the electronic module attached onto the ceramic interconnection module at the top. A calcium silicate Superwool™ blanket (not shown) was wrapped around the LTCC hotplate module.

ELECTRICAL CHARACTERIZATION

The assembled hotplate system was connected to an electrical characterization instrumental setup for the LTCC hotplate temperature regulation. This setup consists of a motherboard, two power amplifiers, four instrumental amplifiers and a LabJack data acquisition card (Labjack U9, Labjack Inc., USA). The motherboard connected all amplifiers and the LabJack for the power and signal communication. The heating voltage was set by computer. The power amplifiers connected with the motherboard and the hotplate system then supplied the amplified power to the hotplate. The instrumental amplifier was connected with the hotplate system to collect the current and voltage signal on the heating tracks. Thus an initial characterization was essential for understanding the actual supply power, the correlation of actual and

measured value of electrical signal as well as the temperature resistance behavior of the heating tracks.

First the relationship of the input voltage (input) and the amplified voltage (output) was calibrated as shown in Fig. 3. The maximum output voltage was limited by our electronics setup to 12.5 V for each heating track. The linearity domain of the outer heating track (T1) lies in the input voltage range of 1-2.5 V, which is considered as the working range for operating T1. For the inner heating track (T2), the working input voltage range is 0.5-2.0 V. All further work was therefore carried out within those linear operation ranges. The curve fitting at the linear parts indicates that the gains of the output voltage for both heating tracks are almost identical. However different baselines at both heating tracks are presented, which can be caused by the systematic errors of the power amplifiers. The relationship of input and output voltage is shown in Eq.1 for T1 and Eq.2 for T2.

$$V_{\text{output}} = 7.429V_{\text{input}} - 5.727 \quad (1)$$

$$V_{\text{output}} = 7.310V_{\text{input}} - 2.076 \quad (2)$$

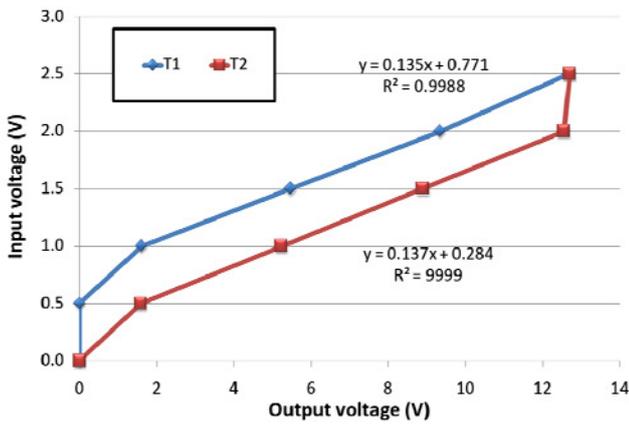


Fig. 3: Voltage amplification calibration

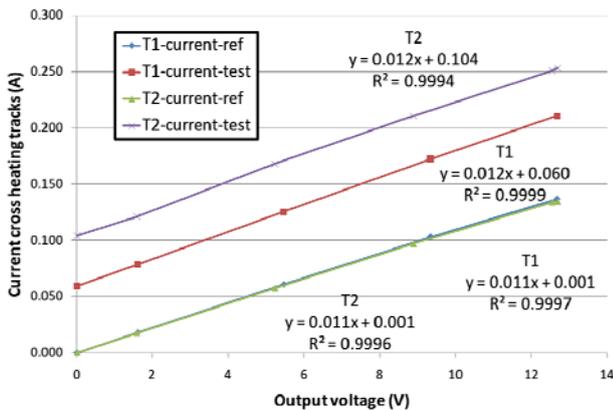


Fig. 4: Current of heating tracks calibration

The current across the heating tracks was characterized by the LabJack (measured value) and measured (reference value) by the multimeter as shown in Fig. 4. The relationship between reference and measured value is established by Eq. 3 for T1 and

Eq. 4 for T2. The “Actual” label means the value that measured by the multimeter. The “Aq.” means the value measured by the LabJack. The baseline of the T2 is larger than that of T1. This shows the systematic errors at the resistor for the inner heating track is higher than that at the outer heating track.

$$C_{T1\text{-actual}} = 0.917C_{T1\text{-aq.}} - 0.054 \quad (3)$$

$$C_{T2\text{-actual}} = 0.917C_{T2\text{-aq.}} - 0.094 \quad (4)$$

The voltage of heating tracks was measured using a multimeter as reference. The working voltage range is in the range of 2-9 V for T1 and 1-11 V for T2, which corresponds to the result of power supply calibration (Fig. 5). The voltage across the heating tracks was measured by the LabJack simultaneously. The value is much smaller than the reference value in both heating tracks. This is because of the voltage divider on the electronic control module that protects the LabJack signal port from the high voltage input. It needs the instrumentation amplifier to provide a high impedance input in order to avoid the interference with the voltage measurement at the voltage divider. The relationship between the actual and acquired value was established for T1 (Eq. 5) and T2 (Eq. 6).

$$V_{T1\text{-actual}} = 19.462V_{T1\text{-aq.}} - 0.742 \quad (5)$$

$$V_{T2\text{-actual}} = 19.169V_{T2\text{-aq.}} + 0.209 \quad (6)$$

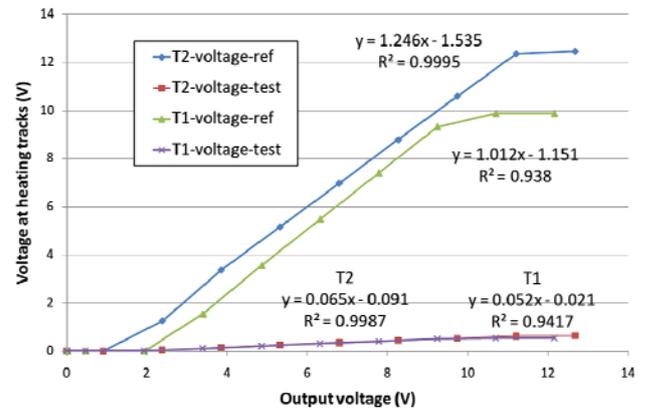


Figure 5. Voltage of heating tracks calibration

A Pt1000 temperature sensor was placed at the center of the hotplate (hot zone). Each data point was collected after a 10 minutes period so that the temperature equilibrium of the hotplate system was reached. With the given power supply, Fig. 6 shows that the temperature can reach up to 190°C by the T1 and 250°C by the T2. This is because more power was applied onto the T2 than the T1. It can be explained by the different positions of the heating tracks. The outside one is closed to the edge of the LTCC hotplate that has larger thermal convection. Thus the power applied to two heating tracks needs to be adjusted in order to achieve homogenous thermal distribution. When both heating tracks were supplied power, the

maximum temperature of the hotplate could reach up to 355°C. However, the thermal distribution and homogeneity are still unknown and will be investigated through IR camera temperature characterization technique at the next stage.

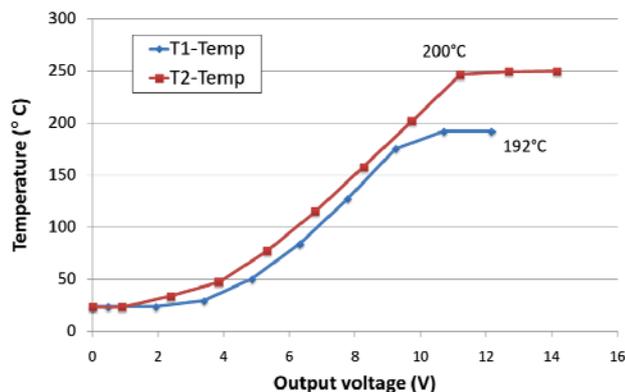


Fig. 6: Temperature of heating tracks (°C)

Each heating track was applied with input power individually. The current and voltage at each heating track were then measured to determine its resistance. Fig.7 shows the resistance of each heating tracks with versus its temperature. The 1st order of temperature coefficient for T1 is 0.0274 and for T2 is 0.0133. Resistance of each heating track was also measured at room temperature giving a resistance of 72.1Ω for the T1 and 62.3 Ω for the T2. Both of them are smaller than the measured value in testing setup. The reason could be caused by the systematic error from the LabJack or the wiring resistance in the test setup.

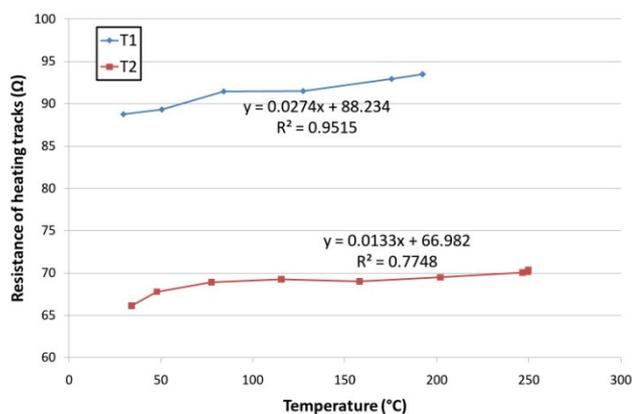


Figure 7. Temperature resistance relationship of AgPd heating tracks

CONCLUSION

A hotplate test platform for a μ -SOFC was developed. The testing system includes a LTCC hotplate module, a ceramic interconnection, an electronic control module, a mechanical carrier and a thermal insulation module. A thick film of AgPd meander was screen printed at bottom of the LTCC hotplate module, which functioned as a self-heating PTC temperature sensor. An external Pt1000 temperature sensor showed that the hotplate platform

with the AgPd heating tracks can reach up to 355°C (currently limited by the electronics). The electrical characterization demonstrated the relationship between the actual and LabJack characterized value of current and voltage at the heating tracks. This information will be used in building up the digital control of the hotplate temperature regulation in National Instrument LabView. The thermal behavior of AgPd resistance was determined. In the future, the thermal distribution on the hotplate will be characterized by IR camera thermal imaging technique. In addition, the power amplifier setup will be improved in order to provide higher power to the hotplate system, allowing it to reach the typical μ -SOFC operating temperature range (500-600°C).

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