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A THIN FILM MULTI-SENSING ARRAY THAT READS SOFCS

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ABSTRACT

The electrode temperature distribution of a solid oxide fuel cell (SOFC) is an important parameter to consider for gaining better insight into the cell performance and its temperature-related degradations. The present efforts of measuring gas channel temperatures do not accurately reveal the cell surface temperature distribution. Therefore, the authors propose a cell-integrated multi-junction thermocouple array to measure the electrode temperature distribution from a SOFC. In this work, the authors deposited a thin film multi-thermocouple array on the cathode of a commercial SOFC and, the temperature of the cell was measured under varying fuel compositions of hydrogen and nitrogen. The multi-thermocouple array showed excellent temperature correlation with the fuel flow rate and with the cell's performance whilst commercial thermocouples showed a very dull response. Further, cell temperature measurements via the multi-thermocouple array enabled detecting potential fuel crossover. This diagnostic approach is applied to commercial SOFCs, yielding insights into key degradation modes including gas-leakage induced temperature instability, its relation to the theoretical OCV and current output, and propagation of structural degradation. It is envisaged that the use of the multi-thermocouple array technique will lead to major improvements in the design of electrochemical energy devices, like FC and batteries and their safety features, and other hard-to-reach devices such as inside an internal combustion engine or turbine blades.

Keywords: solid oxide fuel cells, cathode temperature of SOFC, thin-film thermocouples, multi-thermocouple array, fuel flowrate-OCV relationship

1. INTRODUCTION

Premature degradation of cells and stacks is a significant challenge to ensure the longevity of SOFCs and to make them commercially viable technology to produce cleaner electricity. Among various factors affecting the premature degradation of SOFCs, thermal cycling at high temperatures (usually in a range from 600 °C to 900 °C) and uneven temperature distribution are two dominant factors. Severe mechanical failures such as formation and propagation of cracks and failures in gas sealing are typical temperature-driven failures at cell level, while failures of interconnect sealing is one of the stack level problems aggravated by uneven temperature distribution [1]. Despite aforementioned problems of high operating temperature, some unique meritorious characteristics of SOFC such as fuel flexibility, high energy conversion efficiency, and liberation from the expensive catalyst at the anode, are inherited from the high operating temperature. Therefore, acquiring a comprehensive knowledge of the cell and stack level temperature distribution is vital to mitigate premature degradation while preserving the meritorious characteristics of SOFC. Further, in-situ temperature sensing enables to investigate the detrimental evolutions of temperature profiles induced due to changes in the operating conditions such as current, flow rate, etc. thus, facilitating real-time health monitoring [2].

There are different techniques, such as IR thermometry [3], and Raman Spectroscopy [4], employed to estimate or measure the temperature distribution of an operating SOFC. However, thermocouple thermometry appears to be the most widely used technology [5], [6]. Further, compared to the

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above techniques, thermocouples require relatively low stack modifications to accommodate them in an SOFC system. Thus, they can make a more realistic temperature measurement, which may be strictly comparable to the operating temperature of a cell/ stack under its normal operation. However, a principal drawback of thermocouples in SOFC temperature sensing is its inability to measure the electrode temperature with sufficiently high spatial resolution. To overcome this problem while preserving the meritorious characteristics of thermocouples, especially of thin film thermocouples, the authors proposed cell integrated thin film multi-junction arrays [7].

This paper demonstrates and discusses the application of a thin film multi-thermocouple array to measure the temperature distribution over the cathode of an SOFC under varying fuel compositions. Furthermore, a temperature-OCV correlation, an OCV-fuel composition correlation, and a detection of fuel crossover to cathode are discussed. The authors track for the first time the progression of rapid internal temperature distribution leading up to and during electrochemical activities. This new approach allows us to observe the effects of gas leakage, venting and elevated temperature on the surface of internal layers of commercial SOFCs and to evaluate the influence of SOFC operational engineering on cells safety and performance. Also, another feature of this approach is that it does not require specially arranged equipment or access to high cutting-edge equipment, but the resourceful redeployment of the commercially exploited Seebeck effect for such observations.

2. RESULTS AND DISCUSSIONS

Although the accuracy and sensitivity of temperature measurements from thin-film thermocouples are influenced by the film thickness [8], the performance of K-type thermocouples is independent of the film thickness when the thickness is greater than about 140 nm [9]. Since the fabricated films were much thicker than this threshold value, the performance of the thin film multi-thermocouple array can be considered being independent of the film thickness. Furthermore, the junction sizes were also much larger than the threshold value of 9 µm [10] to get any influence from its size to the performance. Thus, the thin film multi-junction thermocouples can be considered free from any dimensional influence on their performance.

Error! Reference source not found.1 shows the temperature measured by the thin film multi-thermocouple array and the two commercial

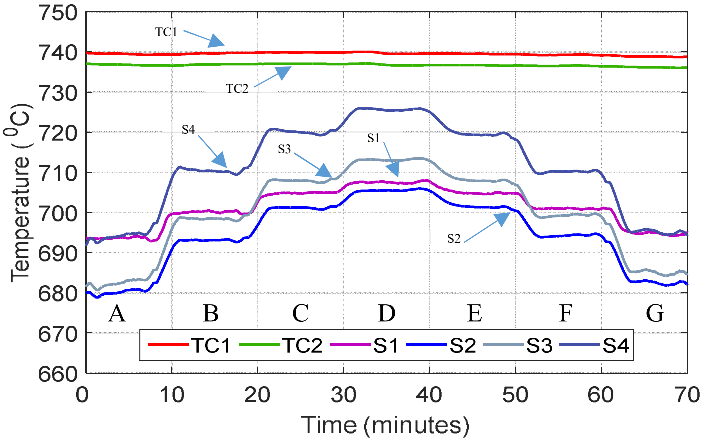

Fig. 1 Temperature response to varying flow rates

thermocouples under varying fuel compositions. Regions marked by letters from *A* to *G* are the flow configurations given in Fig. 1 as well. Temperatures measured by the two thermocouples (RS – Pro), which has faceplate accuracy of +0.004T, recorded approximately 10 °C lower temperature than the furnace's set temperature. Since the thermocouples were placed in the cathode chamber and the cathode was not provided with any air supply, no cooling effect can be expected on commercial thermocouples. Thus, it can be speculated that the observed temperature discrepancy is likely to be an actual temperature gradient present across the furnace. The presence of a temperature gradient between the two commercial thermocouples themselves (*TC1* and *TC2*) supports this argument. Throughout the experiment, the cell temperatures measured by the thin film multi-thermocouple array were noticeably lower than the temperature measured by the commercial thermocouples, which were not more than 5 mm from the cathode. This behavior can be ascribed to a cooling effect that took place on the cell due to the impinging of non-preheated gas on the cell. The sensing point *S2*, which was the closest sensing point to the gas supply (almost right above it), shows the lowest cell temperature throughout the experiment. *S4*, which was located furthest away from the gas inlet, showed the highest overall cell temperature throughout the experiment. Since *S4* is furthest away from the gas inlet, the cooling effect near *S4* should be lower due low chilling resulted by uneven gas distribution at the anode surface. Since the cell was not active, no net heat generation could have taken place on the cell. Thus, the cooling effect predominantly determines the cell temperature distribution. However, although *S1* and *S3* are on the either side of *S2* having equal distances from *S2*, it is impossible to make any comment on the cooling effect at those locations without having comprehensively investigated the flow pattern across the cell; such a study was not conducted.

Importantly, the two commercial thermocouples have failed to follow the dramatic temperature changes took place in the cell, which the thin film MULTI-THERMOCOUPLE ARRAY© could adequately detect. Therefore, it is demonstrated that the cell-integrated thin film MULTI-THERMOCOUPLE ARRAY© could comprehensively detect the cell temperature distribution which subsequently led to the discovery of fuel leakage in the post experimental investigations. As we now can read the temperature distribution of SOFCs internally, we should address this point by addressing the operational temperature of SOFC. we no longer should say that operating a SOFC system at 750˚C but supposed to say like operate them at 750˚C ±45˚C as we now have a tool to detect them accurately.

Internal gas leakage is a major safety concern and it is not always feasible to detect them unless a system-wide inspection is carried out and such tasks are usually performed whilst the system is not in operation. The MULTI-THERMOCOUPLE ARRAY© enables that in-situ detection of gas leakage. This highlights the potential of the MULTI-THERMOCOUPLE ARRAY© both as a diagnostic tool, which could enhance thermal analyses during abuse testing, identifying short-circuiting resistances via dynamic thermal events and as an effective method for thermal model validation. We can further envisage that such in-situ measurements, if incorporated in commercial cells, can drastically cut down on maintenance/shut-off periods and repair cycles, which will improve the commercial feasibility as well as the positive perception/impact into people's daily lives that is expected when these devices hit the mainstream.

A polarization curve is obtained as shown by Fig. 2 . It can be noticed from approximately 72 mA onward that there is a slight downward exponential tendency which indicates a presence of concentration polarization. In parallel to this, the cell temperature also shows a relatively steep increase. Concentration polarization is an irreversibility, which causes entropy generation. With the growth of entropy, the portion of enthalpy being converted to heat increases and part of this heat contributes to rising the cell temperature. Thus, a relatively steep increase of cell temperature can be expected under concentration polarization. Since concentration polarization occurs due to reactant starvation (fuel / oxidant), cell temperature

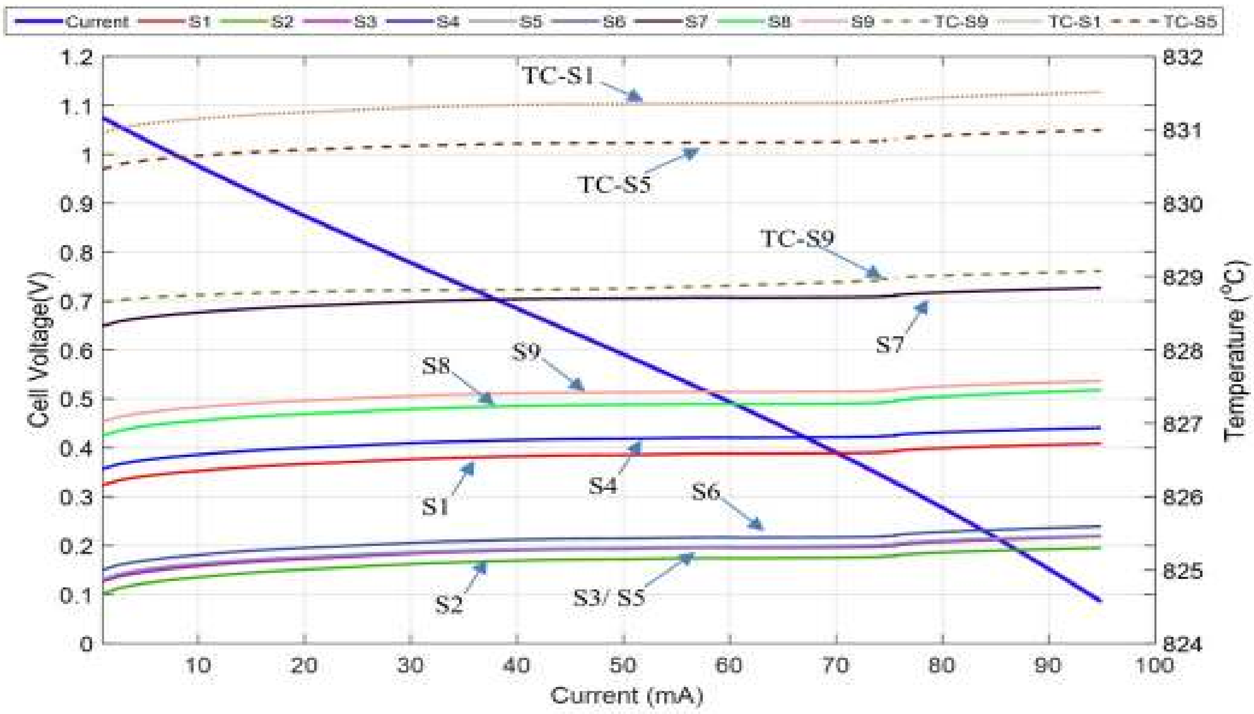

Fig. 2 Polarization curve and cell temperature at 850 °C operating temperature

measurements may be used to identify the regions in a stack which do not get sufficient gas supply.

3. CONCLUSIONS

A thin film MULTI-THERMOCOUPLE ARRAY© having four sensing points was sputter deposited on the cathode of a commercial SOFC cell. The MULTI-THERMOCOUPLE ARRAY© requires only five thermoelements, saving {N-1} thermoelements compared to conventional TCs, to make independent temperature measurements from four sensing points. Thus, it covers less surface area than a set of four thermocouples would cover with its eight thermoelements. The MULTI-THERMOCOUPLE ARRAY© could independently measure the cell temperature despite sharing a thermoelement across its four sensing points.

The cell-integrated MULTI-THERMOCOUPLE ARRAY© monitored the presence of notably high temperature gradients across the cell itself under different flow configurations meanwhile, the commercial thermocouples placed less than 5 mm adjacency to the cathode were completely non-responsive to the temperature variations on the cell. This confirms that near-surface temperature sensing is not sufficient to sense cell temperature distribution of SOFCs.

Cell temperature measured by the thin film MULTI-THERMOCOUPLE ARRAY© shows that cell cooling due to chilled gasses and fuel leakages can introduce significant temperature gradients across the cell, which may in turn potentially lead to cell failure in long term operation due to induction of high level thermal stresses which is undesirable.

The reversibly proportional correlation between the OCV and the cell temperature, as suggested by the Nernst equation could deserve further experimental investigation.

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