EFC2007-39005

SPATIALLY RESOLVED MEASURING TECHNIQUE FOR SOFC

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ABSTRACT

In order to optimize SOFC cells for operation in highly efficient systems a new measuring system with segmented cells has been developed that allows to determine local effects and to identify critical operating parameters during operation. The set-up of the measuring system and experimental results for two examples – influence of hydrogen content and fuel utilization on performance and influence of load on power density and fuel utilization at operation with gasoline reformate as fuel – are presented to demonstrate the potential of the spatially-resolved measuring technique.

INTRODUCTION

Solid oxide fuel cells exhibit the advantage of using hydrocarbons as a fuel without needing an extensive cleaning step. This favors the application of an SOFC as an 'Auxiliary Power Unit' (APU) for vehicles and aircraft where conventional fuels such as gasoline, diesel or kerosene are used. Although large progress has been achieved in the past years in SOFC development the behavior of SOFC cells under technical relevant operating conditions needs to be investigated for a more detailed understanding of the reaction processes, in particular during operation with high power densities and using reformate of hydrocarbons as fuel.

In order to optimize cells for operation in highly efficient systems a measuring technique has been developed at DLR that allows to determine local effects and to identify critical operating parameters. By means of this measuring system with segmented cells current density/voltage characteristics, impedance spectroscopy data and operating temperature can be determined individually at 16 distinct segments.

EXPERIMENTAL DETAILS

Square-shaped cells with an area of 100 cm² which are divided into 16 segments are integrated in a metallic cell housing and sealed with glass seal. The metallic housing is also subdivided into 16 galvanically isolated segments resulting in an active area of 73.96 cm². In order to determine the temperature at each segment thermocouples are introduced. Additionally, 16 capillaries are integrated to collect samples of the anode gas to be analyzed by gas chromatography. More details on the measuring system are given in [1, 2].

The method is quite flexible with regard to the integration of different cell designs: metal-supported cells (MSC) as they are developed and fabricated at DLR according to its spray concept as well as electrolyte- (ESC) and anode-supported cells (ASC) can be characterized. ESC- and ASC-type cells used were supplied by InDEC, Netherlands (ESC2 and ASC2, resp.). With MSC and ASC cells only the cathode is segmented, whereas ESC cells are segmented on both the anode and the cathode side. The ESC2 cell consists of a 45 µm thick NiO/GDC anode, a 90 µm thick YSZ (3 mol% TZ3Y) electrolyte and a 40 µm thick LSM cathode. The ASC2 cell contains a 540 µm thick NiO/YSZ anode with a thin anode functional layer, a 7 µm thick 8YSZ electrolyte, a 7 µm thick YDC interlayer and a 30 µm thick LSCF cathode.

RESULTS AND DISCUSSION

The measuring system described has been applied to locally characterize SOFCs with the segmented cell arrangement. Two examples are given to demonstrate the potential of this spatially-resolved measuring technique: (i) investigation of electrolyte-supported cells (ESC2) under variation of hydrogen content and fuel utilization, and (ii) investigation of anode-supported cells (ASC2) during operation with reformate of gasoline as the fuel.

As a first example for the capability of this new analytical tool the influence of the variation of the hydrogen content and hence of the fuel utilization on the performance of an electrolyte-supported cell (ESC2) was studied. The content of

hydrogen in the fuel gas was varied between 2 and 100 %, the supplementary gas being nitrogen. The results of this investigation are shown in Fig. 1 where the power density and the fuel utilization is depicted in dependence of the hydrogen content for a row of segments: at segment 5 hydrogen enters the cell and at segment 8 it leaves the cell; air enters the cell at segment 8 (counter flow mode). The power density distribution remains homogeneous when the system is operated at low fuel utilizations ($f_u < 25$ %). With higher fuel utilizations significant gradients are observed in power density resulting from both the variation of current density and voltage along the flow channels. At a hydrogen level of 10 % the fuel utilization already reaches nearly 80 % at the fuel outlet at segment 8. Although the fuel utilization is already high the differences in power densities from 149.5 to 184.3 mW/cm² vary only by about 20 %. With even lower hydrogen content the fuel utilization which is calculated from the average current density of the segments reaches levels of nearly 100 % or even above 100 %. Utilizations above 100 % are an artifact of the assumption that the gas distribution between the segments is homogeneous. In reality the current density distributions imply that the middle segment lines are supplied with a higher amount of gas. Since the inhomogeneous gas distribution can not be determined experimentally this systematic error is present in all measurements, but since it affects all concentration values in a similar way it does not influence trends and the comparison of results.
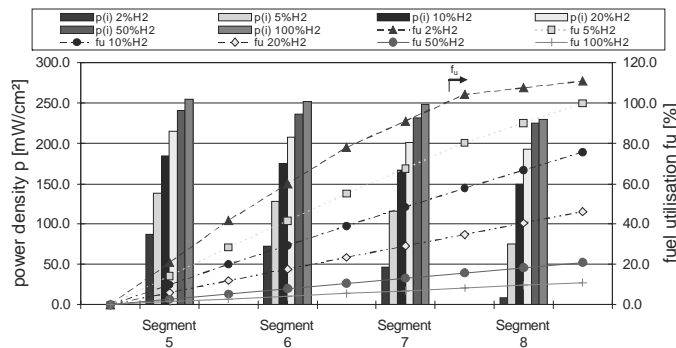

Figure 1. Locally resolved power density distribution (filled bars) and fuel utilization (filled symbols) for different hydrogen concentrations of the electrolyte-supported cell ESC2 (InDEC)

At operation with 2 % hydrogen content segment 8 at the fuel exit contributes only very little to the overall power density (8.8 mW/cm²) compared to 87.1 mW/cm² at segment 5. The differences in the power density at higher hydrogen contents (> 20 %) are about 10 % or less and therefore hardly noticeable. To verify the calculated values of fuel utilization they were compared with values that were measured with the gas chromatograph at 2 %, 10 % and 50 % hydrogen content. The comparison revealed good agreement between the measured and the calculated values.

The results of the spatially-resolved measurements reveal a substantial variation of current density and voltage distribution along the flow path. Particularly at high fuel utilizations inhomogeneous distribution is observed which could lead to anode re-oxidation conditions that might be dangerous for long-term operation.

The second example which is presented covers the operation of an anode-supported cell (ASC2) with a reformate composition as the fuel gas and the electrochemical reaction of the fuel gas components along the flow path. The influence of the area-specific load on the power density and the fuel utilization at operation of a segmented ASC2 cell (counter flow) along a row of segments (segment 9–12) with fuel entrance at segment 9 is shown in Fig. 2; the fuel gas composition was 54.9 % N_2, 16.7 % H_2, 16.5 % CO, 6.6 % CH_4, 2.2 % CO_2, and 3.2 % H_2O, the air flow rate was 0.02 slpm/cm².
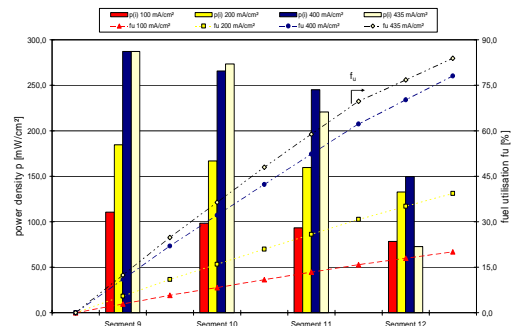

Figure 2: Comparison of power density and fuel utilization along the flow path during variation of the area-specific load of a ASC2 cell (active area: 73.96 cm²); counter flow mode, fuel gas entrance at segment 9, fuel gas exit at segment 12

The results in Fig. 2 reveal an excellent conversion of CO- and CH_4-containing fuel gas with 78.1 % at 400 mA/cm² and with 83.9 % at 435 mA/cm² at the fuel exit. At a current density between 0 and 200 mA/cm² the power density decreases only slightly along the flow path, but at a load of 400 mA/cm² a quite significant and strong reduction of power density at the fuel exit (segment 12) was observed. This behavior is even more pronounced at a further increased current density of 435 mA/cm² of the total cell, segment 12 now shows a very low power density. It seems that the increasing conversion rate at the segments 9–11 causes performance reduction at segment 12 that could result in critical conditions and hence enhanced corrosion at the fuel exit.

REFERENCES

[1] Metzger, P., Schiller, G., and Störmer, A.O., 2004 "SOFC Characteristics along the Flow Path", Proc. 6th European SOFC Forum, M. Mogensen, ed., Vol. 2, pp. 989-999
[2] Metzger, P., Friedrich, K.-A., Müller-Steinhagen, H., and Schiller, G., 2006, „SOFC Characteristics along the Flow Path", Solid State Ionics, 177, pp.2045-2051