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Multi-layer thin-film electrolytes for metal supported solid oxide fuel cells

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HIGHLIGHTS

- Metal-supported solid oxide fuel cells for mobile applications.
- Development of multi-layer electrolytes by means of gas-flow sputtering process.
- First electrochemical cell tests show current densities higher than 2 A cm^{-2} at 0.7 V and 850 °C.

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ABSTRACT

A key to the development of metal-supported solid oxide fuel cells (MSCs) is the manufacturing of gas-tight thin-film electrolytes, which separate the cathode from the anode. This paper focuses the electrolyte manufacturing on the basis of 8YSZ (8 mol.-% Y_2O_3 stabilized ZrO_2). The electrolyte layers are applied by a physical vapor deposition (PVD) gas flow sputtering (GFS) process. The gas-tightness of the electrolyte is significantly improved when sequential oxidic and metallic thin-film multi-layers are deposited, which interrupt the columnar grain structure of single-layer electrolytes. Such electrolytes with two or eight oxide/metal layers and a total thickness of about 4 μm obtain leakage rates of less than 3×10^{-4} hPa dm^3 s^{-1} cm^{-2} (Δp: 100 hPa) at room temperature and therefore fulfill the gas tightness requirements. They are also highly tolerant with respect to surface flaws and particulate impurities which can be present on the graded anode underground. MSC cell tests with double-layer and multilayer electrolytes feature high power densities more than 1.4 W cm^{-2} at 850 °C and underline the high potential of MSC cells.

1. Introduction

Over the last decades, global development and industrializing activities in the field of solid oxide fuel cells (SOFCs) were dominated by two cell technologies, i.e. the anode-supported (ASC) and the electrolyte-supported (ESC) cell. Both cell types have demonstrated highly efficient power generation and cost effective cell manufacturing by using well established ceramic processing technologies such as screen printing and tape casting [1]. Supported by high development efforts, SOFC systems are currently giving their debut in commercial markets, e.g. in stationary power and/or combined heat and power (CHP) applications [2,3].

Besides stationary applications, the interest for mobile and portable power generation has been growing continuously during the past years [12]. SOFC system requirements for such applications being very challenging, e.g. frequent redox- and thermo-cycles as well as short start-up times. It was readily realized that ceramic ASC and ESC technologies do not fully suffice the demands. To meet this challenge, developments to create SOFCs based on a metal-supported cell (MSC) technology were initiated [4–11]. Reinforced by a metallic support, an MSC combines significantly improved mechanical stability with a much enhanced thermal and redox behavior as compared to fully ceramic cell systems, and thus addresses all important requirements for mobile applications.

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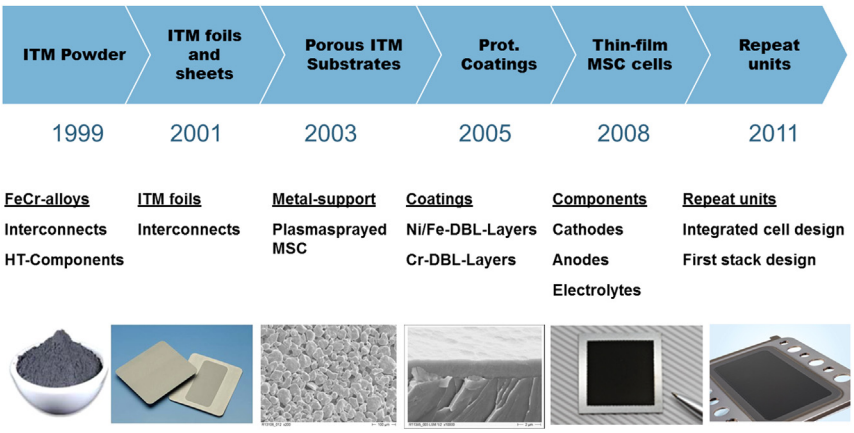

Fig. 1. Milestones of MSC development.

Plansee's activities in the field of component development for the MSC date back to the 1990s. At that time, a ferrite oxide dispersion strengthened Fe–Cr-alloy (trade name ITM) was developed which enables the fabrication of a porous metallic support within a powder-metallurgical (P/M) manufacturing route. This porous ITM substrate can be seen as an outstanding component – as a "backbone" of the whole MSC. Principally, it allows the set-up of thin ceramic cell layers and hence the fabrication of a high performance thin-film MSC. Moreover, this substrate has a strong contribution to the requirements of a mobile cell concept as already mentioned above.

Further milestones of component development are shown in Fig. 1. Due to a manifoldness of detailed cell component development, which has been performed in strong cooperation with Forschungszentrum Jülich (Jülich), the Karlsruhe Institute of Technology (KIT), and the Fraunhofer Institute for Surface Engineering and Thin Films, respectively, a novel MSC concept for mobile applications has been established. In this concept, a novel thin-film electrolyte, which separates the cathode from the anode, paved the way to an outstanding high performance thin-film cell concept.

In the present paper the electrolyte development and the manufacturing process is being presented. Within the scope of a systematic basic and development work a highly potential electrolyte structure, consisting of 8YSZ (8 mol.-% Y_2O_3 stabilized ZrO_2), has been developed by using a physical vapor deposition (PVD) gas flow sputtering (GFS) process. Where a standard structure (single-layer configuration) could be established and discussed in detail elsewhere [15], in this work a significant improvement of the electrolyte structure regarding gas-tightness, lesser defect formation and hence higher layer quality has been focused. The scientific approach was assumed that the gas-tightness of the electrolyte can be significantly improved when sequential oxidic and metallic thin-film multi-layers are deposited in an alternated way. This enables generally to interrupt the columnar grain structure during the growth of such thin-film layers. Electrolytes that were fabricated in this way, with two or eight oxide/metal layers and a total thickness of about 4 μm, achieve leakage rates of lesser than 3×10^{-4} hPa dm^3 s^{-1} cm^{-2} (Δp: 100 hPa in air at RT). In contrast, standard electrolyte structures (single layers) possess a leakage rate which is at least a half an order of magnitude higher. Therefore, this novel structure promises a significant improvement of gas-tightness and hence a higher open circuit cell voltage (OCV). The last one is a basic requirement to achieve high cell performances during cell operation. Furthermore, it could be demonstrated that such structures are also highly tolerant with respect to surface flaws and particulate impurities which can occur on the graded anode underground. Finally, electrochemical tests with cells, operating with such a double and multilayer electrolyte system, could be demonstrated, successfully.

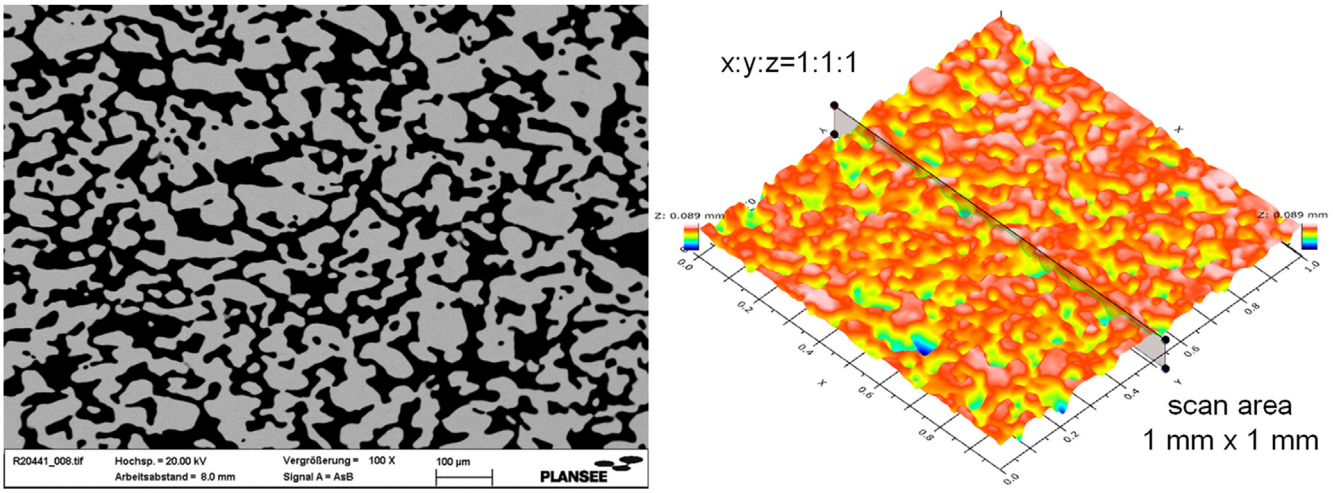

Fig. 2. SEM cross-section of the metallic substrate (left), 3-dimensional optical surface scan of the substrate (x:y:z = 1:1:1, Δz = 0.089 mm) (right) [15].