Publications:

**Durable fuel electrode**

The present invention relates to a composite for an electrode, a composite precursor, a method of manufacturing a composite, and the composite obtained by said method. The invention further relates to an electrode comprising the composite, as well as a solid state electrochemical cell comprising the composite. The invention also relates to the use of the composite as a fuel electrode, solid oxide fuel cell, and/or solid oxide electrolyser. The invention discloses a composite for an electrode, comprising a three-dimensional network of dispersed metal particles, stabilised zirconia particles and pores, wherein the size of the pores is smaller than the size of the metal particles, wherein the size of the metal particles is essentially equal to or smaller than the size of the stabilised zirconia particles, wherein the porosity is below 33, 30, or 29 vol%, more preferably below 26 or 24 vol%, and most preferably below 23, 22, 21, 18, 15, or 13 vol%, and/or wherein the pores are essentially exclusively generated from the volume created by reducing a corresponding metal oxide to the metal particles.

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**A Decade of Solid Oxide Electrolysis Improvements at DTU Energy**

Solid oxide electrolysis cells (SOECs) can efficiently convert electrical energy (e.g. surplus wind power) to energy stored in fuels such as hydrogen or other synthetic fuels. Performance and durability of the SOEC has increased orders of magnitude within the last decade. This paper presents a short review of the R&D work on SOEC single cells conducted at DTU Energy from 2005 to 2015. The SOEC improvements have involved increasing the of the oxygen electrode performance, elimination of impurities in the feed streams, optimization of processing routes, and fuel electrode structure optimization. All together, these improvements have led to a decrease in long-term degradation rate from ~40 %/kh to ~0.4 %/kh for steam electrolysis at -1 A/cm², while the initial area specific resistance has been decreased from 0.44 Ωcm² to 0.15 Ωcm² at -0.5 A/cm² and 750 °C.
Development of Robust Metal-Supported SOFCs and Stack Components in EU METSAPP Consortium

The potential of MS-SOFCs was demonstrated through the previous EU METSOFC project, which concluded that the development of oxidation resistant novel metal-supported solid oxide fule cell (MS-SOFC) design and stack is the requirement to advance this technology to the next level. The following EU METSAPP project has been executed with an overall aim of developing advanced metal-supported cells and stacks based on a robust, reliable and up-scalable technology. During the project, oxidation resistant nanostructured anodes based on modified SrTiO$_3$ were developed and integrated into MS-SOFCs to enhance their robustness. In addition, the manufacturing of metal-supported cells with different geometries, scalability of the manufacturing process was demonstrated and more than 200 cells with an area of
~150 cm$^2$ were produced. The electrochemical performance of different cell generations was evaluated and best performance and stability combination was observed with doped SrTiO$_3$ based anode designs. Furthermore, numerical models to understand the corrosion behavior of the MS-SOFCs were developed and validated. Finally, the cost effective concept of coated metal interconnects was developed, which resulted in 90% reduction in Cr evaporation, three times lower Cr$_2$O$_3$ scale thickness and increased lifetime. The possibility of assembling these cells into two radically different stack designs was demonstrated.

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Mechanical Properties of Supports and Half-Cells for Solid Oxide Electrolysis Influenced by Alumina-Zirconia Composites

In order to improve the durability and robustness of solid oxide electrolysis cells (SOEC) and stacks, it is necessary to improve the strength of its components. In cathode supported SOEC, the main structural component is the Ni(O)-YSZ support. But the strength of the half-cell or cell is also determined by the strength of other weaker components and by the residual stress state induced by the thermal expansion mismatch. In this study, the mechanical properties of Ni(O)-3YSZ supports with a reference composition and with substitution of 3YSZ by 20A3YSZ (3YSZ with 20 wt.% Al2O3) have been tested and compared. The initial interest of this substitution are a decrease of the coefficient of thermal expansion (CTE) mismatch within the half-cell and the fact that 20A3YSZ is stronger than 3YSZ. The influence of the process on the composition, strength, elastic properties and electrical conductivity of the supports have been measured and analyzed. The short and long-term evolution of these properties is linked to the formation of a NiAl2O4 phase. The samples properties were measured at room temperature or high temperature (800 °C) and in oxidized or reduced conditions. The impact of these supports on residual stresses and strength of half-cells is also discussed.

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Dual-role plasticizer and dispersant for ceramic layers

Thus, one aspect of the invention relates to a green ceramic layer comprising a ceramic material, a binder, and a dual-role dispersant and plasticizer, wherein said dual-role dispersant and plasticizer is an organic di- or tri-ester selected from compounds of formula (I), (II), (III) and (IV). Another aspect of the present invention relates to a slurry for use in the manufacturing of a green ceramic layer comprising a ceramic material, a solvent, a binder, and a dual-role dispersant and plasticizer, wherein said dual role dispersant and plasticizer is an organic di- or tri-ester. Further aspects include uses of and methods of manufacturing said green ceramic layers.
A Decade of Improvements for Solid Oxide Electrolysis Cells. Long-Term Degradation Rate from 40%/Kh to 0.4 % Kh

Solid oxide electrolysis cells (SOEC) have the potential for efficient large-scale conversion from electrical energy to chemical energy stored in fuels, such as hydrogen or synthetic hydrocarbon fuels by use of well-known catalysis processes. Key issues for the break-through of this technology are to provide inexpensive, reliable, high performing and long-term stable SOEC for stack and system applications. At DTU Energy (formerly Department of Fuel Cells and Solid State Chemistry, Risø National Laboratory), research within SOEC for more than a decade has led to long-term degradation rates on cell level being improved from 40 %/kh to 0.4 %/kh for tests at -1 A/cm² (figure 1). In this paper, we review the key findings and highlight different performance and durability limiting factors that have been discovered, analyzed and addressed over the years to reach the tremendous increase in long-term stability for SOEC as illustrated by the cell tests in figure 1.

Ni/YSZ electrodes structures optimized for increased electrolysis performance and durability

Cermet Ni/YSZ electrodes are the most commonly applied fuel electrode for solid oxide cells (SOC) both when targeting solid oxide fuel cell (SOFC) applications and when used as solid oxide electrolysis cell (SOEC). In this work we report on the correlation between initial Ni/YSZ microstructure and the resulting electrochemical performance both initially and during long-term electrolysis testing at high current density and high p(H₂O) inlet. Especially, this work focuses on microstructure optimization to hinder Ni mobility and migration during long-term operation and illustrates the key-role of electrode over-potential on the degradation of the Ni/YSZ electrodes in SOEC. We find that for long-term stability for electrolysis at high current densities and high p(H₂O) the as-produced NiO/YSZ precursor electrode should be: 1) As dense as possible, 2) as fine particle and pore sized as possible and 3) the three phases (Ni, YSZ and pore phase) shall be size-matched and well-dispersed. Applying such microstructure optimized Ni/YSZ electrode we show SOEC test results with long-term degradation rate as low as 0.3-0.4%/kh at - 1 A/cm², 800 °C and inlet gas mixture of p(H₂O)/p(H₂):90/10. This enables SOEC operation of such cell for more than 5 years below thermo-neutral potential at these operating conditions.
Solid oxide electrolysis cells, Ni/YSZ electrode, Microstructure, Electrochemical impedance spectroscopy, Performance, Durability
Novel ceramic processing method for substitution of toxic plasticizers

A systematic screening of plasticisers for a polyvinyl butyral based binder system revealed that dibutyl maleate, dibutyl adipate and Pycal 94 are promising and less toxic alternatives to the very harmful but frequently used dibutyl phthalate. Pycal 94 seems especially promising as it unlike the two other candidates did not require a co-plasticiser, such as a polyethylene glycol, thus simplifying the system and reducing the risk of unwanted cross-interactions. An effective and systematic procedure for substitution of the plasticiser, while maintaining chemical compatibility and mechanical properties, was also demonstrated. Incompatible systems were discarded in an initial broad screening while primary systems were further evaluated based on debinding properties, mechanical properties, flow behavior as well as sintering properties of ceramic tapes. The thermomechanical characterization performed on dried drops of binder and their corresponding tapes show strong similarities in the strain/stress profiles, validating the qualitative method used.
The electrochemical performance and stability of the planar metal supported solid oxide fuel cells (MS-SOFC) with two different electrocatalytically active materials, namely, Ni:GDC and Ru:GDC was investigated. Ru:GDC with an ASR of 0.322 Ωcm² performed better compared to Ni:GDC with an ASR of 0.453 Ωcm² at 650°C. The performance of the Ru:GDC infiltrated MS-SOFC is the best measured so far on planar MS-SOFCs. It was observed that the stability of both the electrocatalytically active materials is relatively poor. Microstructure of the anode functional layer appeared to be dense up on the examination. Further optimization of microstructure, electrocatalyst amount and electrocatalyst integration process can improve the long-term stability in particular and electrochemical performance in general.

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Investigation of Novel Electrocatalysts for Metal Supported Solid Oxide Fuel Cells - Ru:GDC

Even though solid oxide fuel cells (SOFCs) have a high potential with respect to efficiency and fuel flexibility they are not yet competitive in terms of cost and durability with conventional chemical energy conversion technologies. The potential cost reduction can be achieved through the development of metal supported SOFCs (MS-SOFCs) by using the cheaper support materials such as stainless steel. Furthermore, MS-SOFCs offer some advantages compared to conventional electrode and electrolyte supported SOFCs such as higher thermal conductivity, ductility in support, which are advantageous in tolerating the vibrations, transient loads, thermal and redox cycling [1-2]. The DTU MS-SOFC design based on ferritic stainless steel requires incorporation of electrocatalyst into the anode functional layer by infiltration methods [3]. Previously, the preferred electrocatalyst has been gadolinium doped ceria (GDC) with small amounts of Ni, which in the following is referred to as Ni:GDC. Recently, studies on Nb-doped SrTiO3 anode based all ceramic electrolyte supported SOFCs have shown that Ru:GDC electrocatalyst is relatively superior in terms of performance and durability than Ni:GDC [4]. In the present study, MS-SOFCs infiltrated with Ru:GDC electrocatalyst are investigated. The Ru:GDC precursor solution was infiltrated into the anode backbone and heat treated in air at different temperatures to remove the organic materials while preventing the corrosion of the metal particles. The morphology and microstructure of the infiltrated electrocatalyst layer was characterized using high-resolution electron microscopy. The electrochemical characterization involved polarization curves and electrochemical impedance spectroscopy (EIS) in the temperature range of 650-750°C. The polarization curve for Ru:GDC infiltrated MS-SOFC on single cell level (active area 16 cm2) is presented in Fig. 1. The fuel utilization corrected polarization resistance, Rp, of 0.322Ωcm2 was measured at 650°C in 20%H2O/H2. This is the lowest Rp reported for any MS-SOFC design to the knowledge of the authors. The durability was lower than expected and this could be due to the loss of percolation of the electrocatalyst. The relatively dense microstructure of the anode functional layer might have resulted in very thin electrocatalyst layer that could become non-percolating layer over the time at the operating temperature. Fig. 1 : Polarization curve of Ru:GDC infiltrated MS-SOFC at 650°C with 20%H2O/H2as fuel and air as oxidant. References: [1]. M.C. Tucker, J. Power Sources, 195 (2010) 4570-4582. [2]. P. Blennow, J. Hjelm, T. Klemenso, S. Ramousse, A. Kromp, A. Leonide, A. Weber, J. Power Sources, 196 (2011) 7117-7125. [3] T. Klemenso, J. Nielsen, P. Blennow, A.H. Persson, T. Stegk, B.H. Christensen, S. Sonderby, J. Power Sources, 196 (2011) 9459-9466. [4] T. Ramos, S. Veltzé, B. R. Sudireddy, P.S. Jørgensen, L. Theil Kuhn, P. Holtappels, Fuel Cells, 14 (2014) 1062-1065. [Figure]
Investigation of Novel Electrocatalysts for Metal Supported Solid Oxide Fuel Cells - Ru:GDC

The electrochemical performance and stability of the planar metal supported solid oxide fuel cells (MS-SOFC) with two different electrocatalytically active materials, namely, Ni:GDC and Ru:GDC were investigated. Ru:GDC with an ASR of 0.322 $\Omega \text{cm}^2$ performed better than Ni:GDC with an ASR of 0.453 $\Omega \text{cm}^2$ at 650°C. The performance of the Ru:GDC infiltrated MS-SOFC is the best measured so far on planar MS-SOFCs. It was observed that the stability of both the electrocatalytically active materials is relatively poor. Microstructure of the anode functional layer appeared to be dense up on the examination. Further optimization of microstructure, electrocatalyst amount and electrocatalyst integration process can improve the long-term stability in particular and electrochemical performance in general.

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Ni/YSZ microstructure optimization for long-term stability of solid oxide electrolysis cells

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Residual stresses and strength of multilayer tape cast solid oxide fuel and electrolysis half-cells
The cost-effectiveness of Solid Oxide Cells production can be improved by introducing "multilayer-tape-casting" (MTC: sequential casting of the layers) and co-sintering of the half-cells. MTC additionally results in more homogeneous layers with strong interfaces. However, the thermal expansion coefficient (TEC) mismatch between the layers, cumulated from high temperature, induces significant residual stresses in the half-cells. Furthermore, it has been observed that MTC half-cells with 4 layers (MTC4: support, fuel electrode, electrolyte and barrier layer) are sometimes more fragile to handle than those with 3 layers (MTC3: without barrier layer). The bending strength of MTC3 and MTC4 under various loading orientations (electrolyte on the tensile or compressive side of the loading) is compared. The analysis, by taking residual stresses into account, shows that the strength of the half-cells with the electrolyte on the compressive side corresponds to the strength of the support. With the loading in the other direction (electrolyte on the tensile side), the origin of the failure is in a different layer for MTC3 (fuel electrode) and for MTC4 (barrier layer). In order to decrease the tensile residual stresses, especially in the outer barrier-layer, possible changes to the layer properties are discussed and some optimization guidelines proposed.

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Development of a Novel Ceramic Support Layer for Planar Solid Oxide Cells

The conventional solid oxide cell is based on a Ni–YSZ support layer, placed on the fuel side of the cell, also known as the anode supported SOFC. An alternative design, based on a support of porous 3YSZ (3 mol.% Y2O3–doped ZrO2), placed on the oxygen electrode side of the cell, is proposed. Electronic conductivity in the 3YSZ support is obtained post sintering by infiltrating LSC (La0.6Sr0.4Co1.05O3). The potential advantages of the proposed design is a strong cell, due to the base of a strong ceramic material (3YSZ is a partially stabilized zirconia), and that the LSC infiltration of the support can be done simultaneously with forming the oxygen electrode, since some of the best performing oxygen electrodes are based on infiltrated LSC. The potential of the proposed structure was investigated by testing the mechanical and electrical properties of the support layer. Comparable strength properties to the conventional Ni/YSZ support were seen, and
sufficient and fairly stable conductivity of LSC infiltrated 3YSZ was observed. The conductivity of 8–15 S cm⁻¹ at 850 °C seen for over 600 h, corresponds to a serial resistance of less than 3.5 m Ω cm² of a 300 μm thick support layer.

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Effects of co-sintering in self-standing CGO/YSZ and CGO/ScYSZ dense bi-layers

Viscoelastic properties and sintering mechanisms of tape-casted gadolinium-doped ceria (CGO), yttrium-stabilized zirconia (YSZ), and scandium–yttrium-stabilized zirconia (ScYSZ) are characterized in order to investigate the reciprocal thermo-mechanical compatibility when arranged as a self-standing bi-layered electrolyte system. The combined use of thermo-mechanical analysis, optical dilatometry, and scanning electron microscopy ensures a systematic characterization of both the individual layers and CGO/YSZ and CGO/ScYSZ bi-layered laminates. The results of the co-firing process of the bi-layers are critical due to the mismatch of thermo-mechanical and sintering properties among the materials. Despite the better sinteractivity of ScYSZ, the self-standing CGO/ScYSZ bilayer presents more challenges in terms of densification compared with the CGO/YSZ bi-layer. In particular, above 1200 C, ScYSZ and CGO show residual porosity, and at higher sintering temperatures, above 1300 C, full densification is completely inhibited by constrained sintering phenomena.
In the last decade there has been a renewed and increased interest in electrolysis using solid oxide cells (SOC). So far the vast majority of results reported on long-term durability of solid oxide electrolysis cells (SOEC) have been obtained using SOC produced and optimized for fuel cell operation; i.e. solid oxide fuel cells (SOFC). However, previous long-term tests have shown that the stability behavior of the Ni/yttria-stabilized-zirconia (Ni/YSZ) fuel electrode may fall out quite differently depending on whether the cell is operated in fuel cell or electrolysis mode at otherwise similar test conditions. Initial work has shown significant microstructural changes of the Ni/YSZ electrode close to the electrolyte interface after long-term steam electrolysis test at -1 A/cm² at 800 °C. The results indicate that it will be advantageous to optimize the electrode structure with the aim of keeping the Ni particles in their required positions in the porous Ni/YSZ cermet close to the electrolyte. In this work we report cell tests and microstructures from reference and long-term tested SOEC with varied initial Ni/YSZ ratio with the aim of investigating the effect of changed Ni/YSZ ratio on long-term stability during steam electrolysis.

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Residual stresses in a co-sintered SOC half-cell during post-sintering cooling

Due to the thermal expansion mismatch between the layers of a Solid Oxide Cell, residual stresses (thermal stresses) develop during the cooling after sintering. Residual stresses can induce cell curvature for asymmetric cells but more importantly they also result in more fragile cells. Depending on the loading conditions, the additional stress needed to break the cells can indeed be smaller due to the initial thermo-mechanical stress state. The residual stresses can for a bilayer cell be approximated by estimating the temperature at which elastic stresses start to build up during the cooling, i.e. the reference temperature (Tref) or the strain difference based on the curvature. This approximation gives good results for bilayers with a defined cooling temperature profile, where the curvature of the bilayer defines a unique balance between the two unknown residual stress states in the two layers. This methodology is however not valid for more layers, as several configurations of residual stresses in the layers can result in the same curvature. Therefore the development of residual stresses of co-sintered multilayer cells during the cooling after sintering is here studied by a finite element model simulation taking into account the elastic response and creep of each layer. The model is validated by measuring the curvature and residual stresses of multi-layer cells.

Shape distortion and thermo-mechanical properties of dense SOFC components from green tape to sintered body

Sintering of ceramic materials is a critical process, especially when the components are shaped as multilayer. Microstructural changes and stresses take place in ceramics as single layer from the green stage to the densification stage, leading to shape distortion, delamination and cracks. The characterization of thermo-mechanical properties, such as viscoelasticity, enables a prediction of microstructural stability of SOFCs. Tape-cast bi-layer structures for CGO/YSZ and CGO/ScYSZ was studied during the thermal processing. Different sintering kinetics of bi-layer tape give rise to localized tensile stresses, which develop a camber in the final sintered body. To analyze the phenomena, shrinkage of SOFC components single layers and camber development of bi-layers were measured in-situ by optical dilatometry. In addition, a thoughtful investigation of the viscoelastic properties of individual layers was carried out by thermo-mechanical analysis (TMA). The results from the different techniques were found complementary and viscous behavior of the layered ceramics was verified.
Durable and Robust Solid Oxide Fuel Cells
The solid oxide fuel cell (SOFC) is an attractive technology for the generation of electricity with high efficiency and low emissions. Risø DTU (now DTU Energy Conversion) works closely together with Topsoe Fuel Cell A/S in their effort to bring competitive SOFC systems to the market. This 2-year project had as one of its’ overarching goals to improve durability and robustness of the Danish solid oxide fuel cells. The project focus was on cells and cell components suitable for SOFC operation in the temperature range 600 – 750 °C. The cells developed and/or studied in this project are intended for use within the CHP (Combined Heat and Power) market segment with stationary power plants in the range 1 – 250 kW/We in mind. Lowered operation temperature is considered a good way to improve the stack durability since corrosion of the interconnect plates in a stack is lifetime limiting at T > 750 °C. The fact that degradation and robustness is not very well explored or understood at operating temperatures below 750 °C, provides motivation for focussing on materials and cells suitable for, and operated in this temperature range.
A significant part of this project was concerned with improved understanding of degradation and failure mechanisms. Improved understanding of performance and lifetime limiting factors will make it possible to develop strategies for counteracting degradation and improving the power density of SOFC based systems, both necessary to advance towards the goals set out in the national plan for SOFC implementation.

Multilayer tape cast SOFC – Effect of anode sintering temperature
Multilayer tape casting (MTC) is considered a promising, cost-efficient, up-scalable shaping process for production of planar anode supported solid oxide fuel cells (SOFC). Multilayer tape casting of the three layers comprising the half cell (anode support/active anode/electrolyte) can potentially be cost-efficient and simplify the half-cell manufacturing process. Fewer sintering steps (co-sintering), as well as fewer handling efforts, will be advantageous for up-scaled production. Previous reports have shown that our laboratory produces mechanically strong, high performing anode supported SOFC, with high reproducibility, by tape casting of the anode support [1]. Recent initial results obtained on SOFC with half-cells produced by successive tape casting (MTC) of anode support, anode and electrolyte layers, followed by cosintering of the half-cell, showed increased performance and stability upon FC operation compared to SOFC with half-cells produced by tape casting of anode support but spraying of active anode and electrolyte [2]. These results have initiated further work on MTC half cells. Initial MTC production results have shown that it is possible to co-sinter the MTC anode half cells in a rather large “temperature-window”. To increase our understanding of the MTC process, obtained microstructures and the resulting electrochemical performance of these SOFC, we here report a study of MTC based cells. The half-cells have been produced and co-sintered at 5 different temperatures from 1255 °C to 1335 °C. This study investigates the effect of the sintering temperature on the anode microstructure analysed via electron microscopy images; and correlate it with electrochemical performance of the anode obtained from full cell testing and analysed via iV-curves and impedance spectroscopy.
Optimization of the strength of SOFC anode supports

During operation solid oxide fuel cells are stressed by temperature gradients and various internal and external mechanical loads, which must be withstood. This work deals with the optimization of the strength of as-sintered anode supported half-cells by imposing changes to production parameters, such as powder milling and sintering temperature. The strength was measured with the ball-on-ring method, and analyzed with a large displacement finite element model. Weibull statistics were used to describe the distribution of strengths. The influence on the Weibull strength of the many different processing parameters was found to be quantifiable in terms of cell porosity to a large extent. The results were validated with an independent set of measurements of strength and stiffness by uniaxial tension and the impulse excitation technique, respectively. For application of the finding in relation to the SOFC technology a mathematical frame to determine the optimal porosity of a SOFC system is presented.
Shape distortion and thermo-mechanical properties of SOFC components from green tape to sintering body

Sintering in ceramic materials is a critical process, especially when these are shaped as multilayer. From the green stage to the densification, the effects of organic additives removal, solid state diffusive phenomena, and either differential expansion or contraction of the layers can have critical effect on the final shape leading also failure, delamination etc. In this work, a tape-cast bi-layer structure for CGO and YSZ-(Sc) was studied during the thermal processing from debinding to the sintering. The bilayered samples undergo to several phenomena of shape instabilities and deformation due to binder burn out, differential shrinkage behavior and to a potential interfacial reaction between the two materials. To analyze the phenomena, shrinkage of SOFC components single layers and bilayered samples were measured insitu by optical dilatometer. The densification mismatch stress, due to the strain rate difference between materials, was calculated using Cai’s model. Camber (curvature) development for in situ co-firing of a bi-layer ceramic green tape has been investigated. Analysis of shape evolution from green to sintered body can be carried out by the thermo-mechanical analysis techniques.
A Monolithic Perovskite Structure for Use as a Magnetic Regenerator

A La$_{0.67}$Ca$_{0.26}$Sr$_{0.07}$Mn$_{1.05}$O$_3$ (LCSM) perovskite was prepared for the first time as a ceramic monolithic regenerator used in a regenerative magnetic refrigeration device. The parameters influencing the extrusion process and the performance of the regenerator, such as the nature of the monolith paste and the influence of the sintering on the adiabatic temperature change, were investigated. Comparisons between the extruded monolithic structure before and after the sintering showed that an increase of the adiabatic temperature change was seen after the sintering. Furthermore, calculations show that the performance of the monolithic structure is potentially superior to a parallel plate regenerator, indicating the potential cost and structural benefit of using such structure, i.e. a mechanically stable ceramic thin wall structure, which can be produced in one processing step.

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Metal-Supported SOFC with Ceramic-Based Anode

Metal-supported solid oxide fuel cells have shown promise to offer several potential advantages over conventional anode (Ni-YSZ) supported cells, such as increased resistance against mechanical and thermal stresses and a reduction in materials cost. The purpose of this work is to illustrate how the metal-supported cell concept can be combined with ceramic-based anode materials, such as Nb-doped SrTiO3. The paper shows that a metal-supported cell can have excellent performance by only having electronically conducting phases in the anode backbone structure, into which electrocatalytically active materials are infiltrated after sintering. Initial area specific resistance as low as 0.3 cm² at 700 °C has been obtained with power densities > 1 Wcm⁻². The initial results on the chemical compatibility, electrochemical performance, and galvanostatic durability of a ceramic based (Nb-doped SrTiO3), zirconia-free anode, in a planar metal-supported SOFC concept is discussed. ©2011 COPYRIGHT ECS - The Electrochemical Society
Ni/YSZ anode – Effect of pre-treatments on cell degradation and microstructures

Anode supported (Ni/YSZ–YSZ–LSM/YSZ) solid oxide fuel cells were tested and the degradation over hundreds of hours was monitored and analyzed by impedance spectroscopy. Test conditions were chosen to focus on the Ni/YSZ anode degradation and all tests were operated at 750°C, a current density of 0.75Acm⁻². Oxygen was supplied to the cathode and the anode inlet gas mixture had a high p(H₂O)/p(H₂) ratio of 0.4/0.6. Commercially available gasses were applied. The effect of different types of pre-treatments on the Ni/YSZ electrode degradation during subsequent fuel cell testing was investigated. Pre-treatments included operating at OCV (4% and 40% H₂O in H₂) prior to fuel cell testing, cleaning of the inlet H₂ gas at 700°C and processing the anode half cell via multilayer tape casting. Analyses of impedance spectra showed that the increase in the charge transfer reaction resistance in the Ni/YSZ (RNi,TPB) was decreased to ¼ or less for the pre-treated and fuel cell tested cells when compared with a non-pre-treated reference tested cell; all operated at
the same fuel cell test conditions. Scanning electron microscopy and image analyses for the non-pre-treated reference tested cell and selected pre-treated cells showed significant differences in the area fractions of percolating nickel both in the active anode and support layer.

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Development of Planar Metal Supported SOFC with Novel Cermet Anode

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Development of Planar Metal Supported SOFC with Novel Cermet Anode

Metal-supported solid oxide fuel cells are expected to offer several potential advantages over conventional anode (Ni-YSZ) supported cells, such as increased resistance against mechanical and thermal stresses and a reduction in materials cost. When Ni-YSZ based anodes are used in metal supported SOFC, electrode material from the active anode layer may interdiffuse with the metallic support during sintering. The purpose of this work is to illustrate how the interdiffusion problem can be circumvented by using an alternative anode design based on porous and electronically conducting layers, into which electrocatalytically active materials are infiltrated after sintering. The paper presents the recent results on the electrochemical performance and durability of the novel planar metal-supported SOFC design. The results presented in the paper show that the novel cell and anode design has a promising performance and durability at a broad range of temperatures and is especially suitable for intermediate temperature operation.

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The establishment of low cost, highly reliable and reproducible manufacturing processes has been focused for commercialization of SOFC technology. A major challenge in the production chain is the manufacture of anode-supported planar SOFC's single cells in which each layer in a layered structure contains a complex microstructure. In order to improve the cell performance as well as reducing the processing costs, it has been found necessary to consider the process chain holistically, because successful manufacture of such a cell and the achievement of optimal final properties depend on each of the processing steps and their interdependence. A large database for several thousand anode-supported SOFCs manufactured annually at the Risø National Laboratory in collaboration with Topsoe Fuel Cell A/S has been constructed. This enables a statistical analysis of the various controlling parameters. Some critical manufacturing elements are discussed along with their impact on product quality.