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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Authors: Brodersen, K. (Intern), Hauch, A. (Intern), Chen, M. (Intern), Hjelm, J. (Intern)
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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 magnitudes 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.

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High performance LaNi$_{1-x}$Co$_x$O$_{3-\delta}$ ($x = 0.4$ to $0.7$) infiltrated oxygen electrodes for reversible solid oxide cells

Oxygen electrodes prepared by infiltration of yttria stabilized zirconia backbone with Ce$_{0.8}$Gd$_{0.2}$O$_{1.95}$ barrier layer and LaNi$_{1-x}$Co$_x$O$_{3-\delta}$ ($x = 0.4$ to $0.7$) catalyst for application in reversible solid oxide cells have been studied. The effect of temperature and Ni:Co ratio on their phase composition, microstructure and electrochemical properties are discussed. It was shown that oxygen electrodes infiltrated with LaNi$_{0.6}$Co$_{0.4}$O$_{3-\delta}$ had the lowest polarization resistance, i.e. 67 m$\Omega$ cm$^2$ at 800 °C. The performance of a fuel electrode supported solid oxide cell with infiltrated oxygen electrode in both fuel cell and electrolysis mode was tested. Electrochemical characterization of the solid oxide cell showed that the resistance contribution from these oxygen electrodes to the overall cell resistance is minor i.e. approximately 20 m$\Omega$ cm$^2$ at a temperature of 700 °C. The cell was also tested in the steam electrolysis mode at a constant current of $-1.0$ A cm$^{-2}$ at 800 °C for 240 h. The oxygen electrode showed reasonable degradation rate with the oxygen electrode resistance of 33 m$\Omega$ cm$^2$ at 700 °C after 240 h of testing.

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Scopus rating (2005): SJR 1.65 SNIP 1.825
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Relation Between Ni Particle Shape Change and Ni Migration in Ni–YSZ Electrodes – a Hypothesis

This paper deals with degradation mechanisms of Ni–YSZ electrodes for solid oxide cells, mainly solid oxide electrolysis cells (SOECs), but also to some extent solid oxide fuel cells (SOFCs). Analysis of literature data reveals that several apparently different and even in one case apparently contradicting degradation phenomena are a consequence of interplay between loss of contact between the Ni–YSZ (and Ni–Ni particles) in the active fine-structured composite fuel electrode layer and migration of Ni via weakly oxidized Ni hydroxide species. A hypothesis that unravels the apparent contradiction and explains qualitatively the phenomena is presented, and as a side effect, light has been shed on a degradation phenomenon in solid oxide fuel cells (SOFCs) that has been observed during a decade.

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Authors: Mogensen, M. B. (Intern), Hauch, A. (Intern), Sun, X. (Intern), Chen, M. (Intern), Tao, Y. (Intern), Ebbesen, S. D. (Intern), Hansen, K. V. (Intern), Hendriksen, P. V. (Intern)
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Scopus rating (2006): SJR 1.194 SNIP 1.228
Scopus rating (2005): SJR 0.45 SNIP 0.501
Scopus rating (2004): SJR 0.232 SNIP 0.215
Study of Operating Parameters for Accelerated Anode Degradation in SOFCs

Solid oxide fuel cell (SOFC) applications require lifetimes of several years on the system level. A big challenge is to demonstrate such exceptionally long lifetimes in ongoing R&D projects. Accelerated or compressed testing are alternative methods to obtain this. Activities in this area have been carried out without arriving at a generally accepted methodology. This is mainly due to the complexity of degradation mechanisms on the single SOFC components as function of operating parameters. In this study, we present a detailed analysis of approx. 180 durability tests regarding degradation of single SOFC components as function of operating conditions. Electrochemical impedance data were collected on the fresh and long-term tested SOFCs and used to de-convolute the individual losses of single SOFC cell components – electrolyte, cathode and anode. The main findings include a time-dependent effect on degradation rates and the domination of anode degradation for the evaluated cell types and operating conditions. Specifically, the steam content as determined by fuel inlet composition, current density and fuel utilization was identified as major parameter, more important than for example operating temperature. The obtained knowledge is adopted to identify optimal operation profiles in order to acquire accelerated testing for lifetime investigation of SOFCs.
Testing of Electrodes, Cells and Short Stacks

The present contribution describes the electrochemical testing and characterization of electrodes, cells, and short stacks. To achieve the maximum insight and results from testing of electrodes and cells, it is obviously necessary to have a good understanding of the fundamental principles of electrochemistry, but it also requires proper test geometries and set up, well-chosen operating conditions for different test purposes, correct probing of voltages and temperatures, and solid knowledge on benefits and drawbacks of different characterization techniques to obtain reliable, accurate, and reproducible electrochemical measurements, and this will be the focus of this chapter. First, the important issue of understanding potential differences and measurements of potentials, which is linked to the choice of proper electrode geometries and test set up configurations for electrode and cell testing, is presented. Then probing of voltages and temperatures, choice of sealing and contacting, as well as considerations regarding the choice of operating conditions for different purposes mainly for single cell testing are outlined. Having considered optimization of test set up, geometries, and the selection of optimal operating conditions, the details of measurement of the electrochemical performance of the electrode, cell, or stack are explained. As part of this, the concept of area specific resistance (ASR) and how DC and AC methods can be used and optimized to provide not only the total ASR, but also the electrochemical characterization of specific parts (electrolyte, each electrode) in a full cell are described. Some experimental results are provided including illustrative examples of breakdown of losses in full cells and determination of their temperature and gas composition dependencies, and finally, challenging issues, such as the effects of impurities and the problem of leakage in cell testing, are discussed as well.

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, Riso 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.
In-Situ Formed Ce$_{0.8}$Gd$_{0.2}$O$_{1.9}$ Barrier Layer on Yttria Stabilized Zirconia Back-Bone for Infiltrated Oxygen Electrodes

Solid oxide cells (SOCs) would be economically more favorable with lower operating temperature. Currently the target temperature is between 550 °C and 750 °C. Such low operation temperatures would reduce thermally activated degradation phenomena and would allow the use of cheaper materials. However, reduction of the operating temperature increases the ohmic and electrode polarization losses of the cells.

New Hypothesis for SOFC Ceramic Oxygen Electrode Mechanisms

A new hypothesis for the electrochemical reaction mechanism in solid oxide cell ceramic oxygen electrodes is proposed based on literature including our own results. The hypothesis postulates that the observed thin layers of SrO-La$_2$O$_3$ on top of ceramic perovskite and other Ruddlesden-Popper structured electrode materials are sufficiently electron and oxygen ion conducting to provide reaction sites despite that the bulk phase of such an oxide layer is insulating. We claim that a few nanometer thin layer of mixed SrO-La$_2$O$_3$ that contains some dissolved transition metal and some impurities plus two space charge layers – one towards the gas phase and the other towards the perovskite – will be sufficiently oxide ion (vacancy) and electron conducting to support the electrode process. We also present some considerations about a possible mechanism of improved electrodes.
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.

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Relation between shape of Ni-particles and Ni migration in Ni-YSZ electrodes – a hypothesis

This is an attempt to explain a phenomenon of total depletion of Ni next to the electrolyte in Ni-YSZ cermet electrodes in solid oxide electrolysis cells during electrolysis at high current density/overpotential. Intuitively, we would think that Ni would always migrate down the steam partial pressure (pH$_2$O) gradient as previously observed [1], but in the present cases Ni seems to migrate up the pH$_2$O gradient. However, it is also observed that there is a preceding phase in this Ni-YSZ electrode degradation, namely that the Ni-particles closest to the YSZ electrolyte loose contact to each other. This means that the active three phase boundary (TPB) moves away from the electrolyte and causes a significant increase in the ohmic resistance as is also observed in electrochemical impedance spectra.

General information
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Study of variables for accelerating lifetime testing of SOFCs

Solid oxide fuel cell (SOFC) applications require lifetimes of several years on the system level. A big challenge is to proof/confirm/demonstrate such exceptionally long lifetimes. Accelerated or compressed testing are possible methods. Activities in this area have been carried out without arriving at a generally accepted result. First accelerated testing approaches were performed under non-steady operation conditions (current cycling, temperature cycling) by different researchers [1, 2]. However, cycling conditions seemed to have no significant impact on degradation mechanisms. Furthermore, tests done at different current load cycling profiles revealed a strong deviation between predicted and measured lifetime [3]. In this study, we present a detailed analysis of durability results for degradation mechanisms of single SOFC components as function of operating conditions. Electrochemical impedance data is collected and used to de-convolute the individual losses of single SOFC cell components – electrolyte, cathode and anode. The obtained knowledge is adopted to identify operation profiles and appropriate stresses in order to execute appropriate accelerated testing for lifetime investigation of SOFCs.

Elektrolyse gør al energi fra vindmøller værdifuld

Elektrolyse gør al energi fra vindmøller værdifuld
Er der vedvarende energi nok til os alle?: om brændselsceller og elektrolyseceller til effektiv energikonvertering

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

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Sulfur Poisoning of Ni/stabilized-zirconia Anodes: Effect on Long-Term Durability

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Triple phase boundary specific pathway analysis for quantitative characterization of solid oxide cell electrode microstructure

The density and percolation of Triple phase boundary sites are important quantities in analyzing microstructures of solid oxide fuel cell electrodes from tomography data. However, these measures do not provide descriptions of the quality of the TPB sites in terms of the length and radius of the pathways through which they can be reached. New methods for performing TPB specific pathway analysis on 3D image data are introduced, analyzing the pathway properties of each TPB site in the electrode structure. The methods seek to provide additional information beyond whether the TPB sites are percolating or not by also analyzing the pathway length to the TPB sites and the bottleneck radius of the pathway. We show how these methods can be utilized in quantifying and relating the TPB specific results to cell test data of an electrode reduction protocol study for Ni/Scandia-and-Yttria-doped-Zirconia (Ni/ScYSZ) anodes. A study of the TPB density and particle size distribution alone did not provide an explanation for the differences observed in electrode performance. However, the analysis of pathway lengths to the TPBs and the bottleneck radii to reach these TPB sites provided valuable microstructural insight that supported the findings from the electrochemical characterization of the Ni/ScYSZ anodes.
Electrochemical characterization of $\text{La}_{0.6}\text{Ca}_{0.4}\text{Fe}_{0.8}\text{Ni}_{0.2}\text{O}_3$ cathode on $\text{Ce}_{0.8}\text{Gd}_{0.2}\text{O}_{1.9}$ electrolyte for IT-SOFC

For Solid Oxide Fuel Cells (SOFCs) to become an economically attractive energy conversion technology, suitable materials and structures which enable operation at lower temperatures, while retaining high cell performance, must be developed. Recently, the perovskite-type $\text{La}_{0.6}\text{Ca}_{0.4}\text{Fe}_{0.8}\text{Ni}_{0.2}\text{O}_3$ oxide has shown potential as an intermediate temperature SOFC cathode. An equivalent circuit describing the cathode polarization resistances was constructed from analyzing impedance spectra recorded at different temperatures in oxygen. A competitive electrode polarization resistance is reported for this oxygen electrode using a $\text{Ce}_{0.8}\text{Gd}_{0.2}\text{O}_{1.9}$ electrolyte, determined by impedance spectroscopy studies of symmetrical cells sintered at 800 _°C and 1000 _°C. Scanning electron microscopy (SEM) studies of the symmetrical cells revealed the absence of any reaction layer between cathode and electrolyte, and a porous electrode microstructure even when sintered at a temperature of only 800 _°C. The performance of this cathode shows favorable oxygen reduction reaction (ORR) properties potentially making it an excellent choice for IT-SOFC application. © 2014, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.
High Temperature Electrolysis in Alkaline Cells, Solid Proton Conducting Cells, and Solid Oxide Cells

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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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Sulfur Poisoning of SOFC Anodes: Effect of Overpotential on Long-Term Degradation

Sulfur impurities in carbon containing fuels for solid oxide fuel cells (SOFC), e.g. natural gas and biogas, typically lead to significant losses in performance due to the sulfur sensitivity of Ni/yttria-stabilized-zirconia (YSZ) anodes for SOFC. Full cells having Ni/YSZ anodes have been characterized during long-term galvanostatic operation in internal reforming gas mixture (CH4/H2O/H2:30/60/10), with 2 ppm H2S exposure to the anode for 500 hours at 850°C, at different current densities. This work focus on the long-term effect of H2S exposure over a few hundreds of hours; and describes and correlates the observed evolution of anode performance, over hundreds of hours, with sulfur exposure at low cell overpotential (low current density) and at high overpotential (high current density) with and without H2S exposure. For tests at low overpotential with H2S exposure only a reversible loss in performance was observed and post-mortem SEM analysis showed an intact Ni/YSZ anode microstructure. For tests at high cell overpotential the H2S exposure caused both a reversible loss in performance and an irreversible long-term degradation. Post-mortem SEM analysis of the Ni/YSZ anode from this tests showed increased porosity and lack of percolating Ni in the few microns of the anode closest to the anode/electrolyte interface.
Electrochemical characterization of La$_{0.6}$Ca$_{0.4}$Fe$_{0.8}$Ni$_{0.2}$O$_{3-\delta}$ perovskite cathode for IT-SOFC

Electrolyte supported symmetric cells featuring La$_{0.6}$Ca$_{0.4}$Fe$_{0.8}$Ni$_{0.2}$O$_{3}$ (LCFN) electrodes are studied by electrochemical impedance spectroscopy. The aim is to describe the polarization losses of this mixed ionic electronic conductor electrode at various cell operating conditions for cells sintered at different temperatures. An equivalent circuit describing the cathode polarization resistances was constructed from analyzing impedance spectra recorded at different oxygen partial pressures and temperatures. Favorable oxygen reduction reaction properties are demonstrated for the LCFN cell sintered at 750 °C with a polarization resistance of 0.05 Ω cm$^2$ at an operating temperature of 800 °C in pure...
Microstructural Degradation of Ni/YSZ Electrodes in Solid Oxide Electrolysis Cells under High Current

Ni/yttria stabilized zirconia (YSZ) supported solid oxide electrolysis cells (SOECs) were exposed to long-term galvanostatic electrolysis tests, under different testing conditions (temperature, gas composition, current density etc.) with an emphasis on high current density (above ~1 A/cm²). Detailed post-mortem characterizations were carried out to investigate microstructural changes after long-term galvanostatic tests, focusing on the Ni/YSZ electrode. Formation of ZrO₂ nano-particles on Ni surfaces was observed in cells exposed to ~1 or ~1.5 A/cm² at 800 or 850°C, but not in those tested at current densities below ~0.75 A/cm². The formation of ZrO₂ nano-particles deteriorates Ni percolation and presumably decreases the number of active triple phase boundaries (TPBs) and is therefore considered a degradation phenomenon. It is hypothesized that the degradation of the Ni surface is a result of Ni-YSZ interfacial reactions, taking place under the conditions prevailing under strong polarization. A mechanism for the formation of ZrO₂ nano-particles on the Ni surface under the electrolysis cell testing is proposed and the possibility of Ni-YSZ interfacial reactions under such conditions (T, p(O₂)) is further elucidated by thermodynamic calculations.

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Scopus rating (2007): SJR 1.58 SNIP 1.325
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Scopus rating (2005): SJR 1.519 SNIP 1.484
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Scopus rating (2002): SJR 2.147 SNIP 1.646
Scopus rating (2001): SJR 1.651 SNIP 1.738
Scopus rating (2000): SJR 1.788 SNIP 1.708
Microstructure characterisation of solid oxide electrolysis cells operated at high current density

High temperature solid oxide cells can be operated either as fuel cells or electrolysis cells for efficient power generation or production of hydrogen from steam or synthesis gas (H₂ + CO) from steam and CO₂ respectively. When operated under harsh conditions, they often exhibit microstructural degradation of cell components in relation to the loss of electrochemical performance specific to the mode of operation. Thus descriptive microstructure characterization methods are required in combination with electrochemical characterization methods to decipher degradation mechanisms.

In the present work, microstructure evolution of the Ni-yttria stabilized zirconia (YSZ) is followed as a function of galvanostatic steam electrolysis testing at current densities between -0.5 and -1.0 A cm⁻² for periods of up to 750 hours at 800 °C. The volume fraction and size of the percolating Ni particles was statistically quantified using the mean linear intercept method as a function of current density and correlated to increases in serial resistance.

The above structural changes are then compared in terms of electrode degradation observed during the co-electrolysis of steam and CO₂ at current densities up to -1.5 A cm⁻². In this study, the formation of ZrO₂ based nano particles at the Ni-pore interface is responsible for the loss of Ni-YSZ particle contact and thus loss of triple phase boundary. Formation of similar nano particles at Ni internal grain boundaries is also thought to be responsible for loss of Ni percolation.

Modeling degradation in SOEC impedance spectra

Solid oxide cell (SOC) performance is limited by various processes. One way to investigate these processes is by electrochemical impedance spectroscopy. In order to quantify and characterize the processes, an equivalent circuit can be used to model the SOC impedance spectra (IS). Unfortunately, the optimal equivalent circuit is often unknown and to complicate matters further, several processes contribute to the SOC impedance - making detailed process characterization difficult. In this work we analyze and model a series of IS measured during steam electrolysis operation of an SOC. During testing, degradation is only observed in the Ni/YSZ electrode and not in the electrolyte or the LSM/YSZ electrode. A batch fit of the differences between the IS shows that a modified Gerischer element provides a better fit to the Ni/YSZ electrode impedance than the frequently used RQ element - albeit neither equivalent circuit provides a perfect fit. However, modeling with the Gerischer element indicates that the Ni/YSZ electrode performance decrease, relates to an electrochemical reaction resistance increase at the electrode triple phase boundaries. © 2013 The Electrochemical Society.
Optimizing solid oxide fuel cell cathode processing route for intermediate temperature operation

For Solid Oxide Fuel Cells (SOFCs) to become an economically attractive energy conversion technology suitable materials which allow operation at lower temperatures, while retaining cell performance, must be developed. At the same time, the cell components must be inexpensive - requiring both low-priced raw material and cost-effective production techniques. In this work the perovskite-type La0.6Ca0.4Fe0.8Ni0.2O3 (LCFN) oxide has been used in order to optimize intermediate temperature SOFC cathode processing route. The advantages this material presents arise from the low temperature powder calcination (∼600°C) and electrode sintering (∼800°C) of LCFN electrodes, making them a cheaper alternative to conventional SOFC cathodes. An electrode polarization resistance as low as 0.10Ωcm² at 800°C is reported, as determined by impedance spectroscopy studies of symmetrical cells sintered at a range of temperatures (800-1000°C). Scanning Electron Microscopy (SEM) studies revealed porous electrode microstructures, even when sintered at a temperature of just 800°C. The competitive performance of the electrodes sintered at low temperatures, combined with the low raw material cost, make these electrodes an excellent potential choice for SOFC cathodes. In this work a new cathode processing technique is presented which provides a more economical, lower temperature SOFC production route with no detrimental effect on device efficiency. © 2012 Elsevier Ltd.
Sulfur Poisoning of Ni/stabilized-zirconia Anodes – Effect on Long-Term Durability

Sulfur impurities in carbon containing fuels for solid oxide fuel cells (SOFC), e.g. natural gas and biogas, can lead to significant losses in performance due to the sulfur sensitivity of Ni/YSZ SOFC anodes. Full cells having Ni/YSZ and...
Ni/ScYSZ anodes have been characterized during long-term galvanostatic operation in internal reforming gas mixture (CH4/H2O/H2:30/60/10), with 2 ppm H2S exposure to the anode, at different current densities. The aim was not only to investigate the well-known initial performance drop associated with adsorbed sulfur in the Ni/stabilized-zirconia anodes, but also to focus on the long-term effect over a few hundred of hours. This work describes and correlates the observed evolution of anode performance, over hundreds of hours, with sulfur poisoning with the different operating conditions.

**General information**

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Organisations: Department of Energy Conversion and Storage, Applied Electrochemistry, Fundamental Electrochemistry
Authors: Hauch, A. (Intern), Hagen, A. (Intern), Hjelm, J. (Intern), Ramos, T. (Intern)
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.214 SNIP 0.246
BFI (2013): BFI-level 1
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ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.262 SNIP 0.284
ISI indexed (2011): ISI indexed no
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Scopus rating (2010): SJR 0.247 SNIP 0.245
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.241 SNIP 0.266
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**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 kWe 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.
Production of "Green Natural Gas" Using Solid Oxide Electrolysis Cells (SOEC): Status of Technology and Costs

This paper gives arguments in favour of using green natural gas (GNG) as storage media for the intermittent renewable energy sources. GNG is here defined as being CH4, i.e. methane, often called synthetic natural gas or substitute natural gas (SNG), produced using renewable or at least CO2 neutral energy sources only. Also dimethyl ether (DME = (CH3)2O), which might be called Liquefied Green Gas, LGG, in analogy to Liquefied Petroleum Gas, LPG, because DME has properties similar to LPG. It further gives a short review of the state of the art of electrolysis in general and SOEC in particular. Production of synthesis gas (H2 + CO) from CO2 and H2O using SOEC technology is evaluated. GNG and LGG can be produced from synthesis gas (or short: syngas) by means of well established commercially available catalysis technology. Finally, estimations of costs and efficiencies are presented and the relative importance of cost and efficiency is briefly discussed.

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Links: http://proceedings.wgc2012.com

Durability of Solid Oxide Cells

In recent years extended focus has been placed on monitoring and understanding degradation mechanisms in both solid oxide fuel cells and solid oxide electrolysis cells. The time-consuming nature of degradation experiments and the disparate conclusions from experiment reproductions indicates that not all degradation mechanisms are fully understood. Traditionally, cell degradation has been attributed to the materials, processing and cell operating conditions. More recently, focus has been placed on the effect of raw material and gas impurities and their long-term effect on cell degradation. Minor impurities have been found to play a significant role in degradation and in some cases can overshadow the cell operation condition related degradation phenomenon. In this review, several degradation diagnostic tools are discussed, a benchmark for a desirable degradation rate is proposed and degradation behaviour and mechanisms are discussed. For ease of navigation, the review is separated into the various cell components – fuel electrode, electrolyte and oxygen electrode. Finally, nano-particle impregnate stability is discussed.

General information
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Authors: Knibbe, R. (Intern), Hauch, A. (Intern), Hjelm, J. (Intern), Ebbesen, S. D. (Intern), Mogensen, M. B. (Intern)
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Main Research Area: Technical/natural sciences

Publication Information
Journal: Green
Volume: 16
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ISSN (Print): 1869-876X
Ratings:
Electrochemical characterisation of solid oxide cell electrodes for hydrogen production

Oxygen electrodes and steam electrodes are designed and tested to develop improved solid oxide electrolysis cells for H2 production with the cell support on the oxygen electrode. The electrode performance is evaluated by impedance spectroscopy testing of symmetric cells at open circuit voltage (OCV) in a one-atmosphere set-up. For the oxygen electrode, nano-structured La0.75Sr0.25MnO3 (LSM25) is impregnated into a LSM25/yttria stabilised zirconia (YSZ) composite, whereas for the steam electrode, nano-structured Ni and Ce0.8Gd0.2O2−δ (CGO) is impregnated into a Sr0.94Ti0.9Nb0.10O3−δ (STN) backbone. In the present study, the best performing oxygen electrode is a LSM25-YSZ composite with 20% porosity and impregnated with a LSM25 solution measuring a polarisation resistance (Rp) of 0.12 Ω cm² at 850 °C in oxygen. For the steam electrode, the best performance is obtained for a STN backbone, sintered at 1200 °C and impregnated with CGO/Ni, with an Rp of 0.08 Ω cm² at 850 °C in 3% H2O/H2.

General information
State: Published
Authors: Bernuy-Lopez, C. (Intern), Knibbe, R. (Intern), He, Z. (Intern), Mao, X. (Intern), Hauch, A. (Intern), Nielsen, K. A. (Ekstern)
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DOI: 10.1515/GREEN.2011.015
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Electrolysis for Integration of Renewable Electricity and Routes towards Sustainable Fuels

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemical Evaluation, Microstructures and Interfaces, Electroceramics
Publication date: 2011

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Main Research Area: Technical/natural sciences
Workshop: 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms, Aarhus, Denmark, 25/10/2011 - 25/10/2011
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electrolysis for Integration.pdf
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High performance anode supported SOFC produced by multilayer tape casting

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Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemical Evaluation
Authors: Brodersen, K. (Intern), Hauch, A. (Intern), Hjalmarssson, P. (Intern), Hjelm, J. (Intern)
Publication date: 2011
Main Research Area: Technical/natural sciences
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High performance anode.pdf
Source: orbit
Source-ID: 314319
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.

General information

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Organisations: Electrochemical Evaluation, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Microstructures and Interfaces, Ceramic processing, Electrochemistry
Authors: Hauch, A. (Intern), Jørgensen, P. S. (Intern), Brodersen, K. (Intern), Mogensen, M. B. (Intern)
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Scopus rating (2015): SJR 1.945 SNIP 1.686
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.983 SNIP 2.071
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.985 SNIP 2.138
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.293 SNIP 2.016
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.247 SNIP 2.181
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.297 SNIP 1.981
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.117 SNIP 1.793
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.968 SNIP 1.726
Scopus rating (2007): SJR 1.597 SNIP 1.489
Scopus rating (2006): SJR 1.8 SNIP 2.224
Scopus rating (2005): SJR 1.65 SNIP 1.825
Scopus rating (2004): SJR 1.852 SNIP 1.818
Scopus rating (2003): SJR 1.66 SNIP 1.583
Ni/YSZ electrode degradation studied by impedance spectroscopy — Effect of p(H₂O)

Anode supported solid oxide fuel cells have been tested and the degradation over time was monitored and analyzed by impedance spectroscopy. Reproducibility of initial cathode, anode and electrolyte performance was obtained. Anode (Ni/YSZ) degradation was analyzed for tests applying p(H₂O) of 0.2 atm, 0.4 atm and 0.6 atm at 750 °C and 0.75 A/cm². The anode degradation could be well described by the equation: \( R_{Ni,TPB}(t) = R_{Ni,0} + \Delta R \times (1 - \exp(-t/\tau)) \). The initial resistance and total increase for the Ni–YSZ charge transfer resistance, \( R_{Ni,0} \) and \( \Delta R \), were similar for all tests (i.e. not directly correlated with p(H₂O)), but the characteristic time, \( \tau \), for the anode degradation was significantly higher for the test at p(H₂O) = 0.2 atm than at p(H₂O) of 0.4 atm and 0.6 atm.

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Authors: Hauch, A. (Intern), Mogensen, M. B. (Intern), Hagen, A. (Intern)
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Scopus rating (2015): SJR 0.819 SNIP 1.033
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.843 SNIP 1.304
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.902 SNIP 1.274
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.055 SNIP 1.258
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.383 SNIP 1.621
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.459 SNIP 1.503
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.507 SNIP 1.483
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.516 SNIP 1.621
Complementary techniques for solid oxide electrolysis cell characterisation at the micro- and nano-scale

High-temperature steam electrolysis by solid oxide electrolysis cells (SOEC) is a method with great potential for transforming clean and renewable energy from non-fossil sources to synthetic fuels such as hydrogen, methane or dimethyl ether, which have been identified as promising alternative energy carriers. With the same technology, fuel gas can be used in a very efficient way to reconvert chemically stored energy into electrical energy, since SOECs also work in the reverse mode, operating as solid oxide fuel cells (SOFC). As solid oxide cells (SOC) perform at high-temperatures (700–900 °C), material degradation and evaporation can occur, e.g., from the cell-sealing material, leading to poisoning effects and aging mechanisms that decrease the cell efficiency and long-term durability. To investigate such cell degradation processes, thorough examination of SOCs often requires a chemical and structural characterisation at a microscopic and nanoscopic level. The combination of different microscopic techniques such as conventional scanning electron microscopy (SEM), electron probe microanalysis (EPMA) and the focused ion beam (FIB) preparation technique for transmission electron microscopy (TEM) allows for post-mortem analysis at a multi-scale level. These complementary techniques can be used to characterise structural and chemical changes over a large and representative sample area (micro-scale) as well as at the nano-scale level for selected sample details. This article presents a methodical approach...
for the structural and chemical characterisation of changes in aged cathode-supported electrolysis cells produced at Risø DTU, Denmark. Additionally, we present results from the characterisation of impurities at the electrolyte/hydrogen interface caused by evaporation of sealing material.

**General information**

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Organisations: Electrochemical Evaluation, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry, University of Fribourg, University of Freiburg
Authors: Wiedenmann, D. (Ekstern), Hauch, A. (Intern), Grobety, B. (Ekstern), Mogensen, M. B. (Intern), Vogt, U. (Ekstern)
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Scopus rating (2015): SJR 1.294 SNIP 1.319
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.212 SNIP 1.494
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.278 SNIP 1.467
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.515 SNIP 1.729
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.456 SNIP 1.837
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.589 SNIP 1.871
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.333 SNIP 1.885
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.401 SNIP 2.096
Scopus rating (2007): SJR 1.279 SNIP 2.201
Scopus rating (2006): SJR 1.073 SNIP 2.161
Scopus rating (2005): SJR 1.107 SNIP 1.787
Scopus rating (2004): SJR 1.225 SNIP 1.626
Scopus rating (2003): SJR 1.003 SNIP 1.319
Scopus rating (2002): SJR 0.763 SNIP 1.157
Scopus rating (2001): SJR 0.487 SNIP 1.185
Scopus rating (2000): SJR 0.518 SNIP 0.866
Scopus rating (1999): SJR 0.382 SNIP 0.897
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Source-ID: 263924
Publication: Research - peer-review › Conference article – Annual report year: 2010
Ni/YSZ electrode degradation studied by impedance spectroscopy: Effects of gas cleaning and current density

Anode supported (Ni/YSZ–YSZ–LSM/YSZ) solid oxide fuel cells were tested and the degradation over time was monitored and analyzed by impedance spectroscopy. Test conditions were chosen to focus on the anode degradation and all tests were operated at 750 °C. O2 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. Cells were tested over a few hundred hours applying varying current densities (OCV, 0.75 A/cm² and 1 A/cm²). To investigate the effects of possible impurities in the inlet gas stream on the anode degradation, tests were set-up both with and without gas cleaning. Gas cleaning was done by passing the H2 over porous nickel at room temperature. It was found that cleaning of the inlet H2 gas more than halved the anode degradation under current load. For tests at OCV the increase in the Ni–YSZ charge transfer reaction resistance changed from 0.10 Ωcm² to become negligible (below 0.002 Ωcm²) upon applying H2 gas cleaning over the couple of hundred of hours of testing. Both for tests with and without H2 gas cleaning applied, it was surprisingly found that operating the solid oxide fuel cells at OCV prior to fuel cell testing provided fuel cell tests with minimal/negligible anode degradation compared to tests where fuel cell testing was started immediately after initial characterization of the cells.

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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.819 SNIP 1.033
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.843 SNIP 1.304
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.902 SNIP 1.274
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Scopus rating (2012): SJR 1.055 SNIP 1.258
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.383 SNIP 1.621
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.459 SNIP 1.503
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.507 SNIP 1.483
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.516 SNIP 1.621
Scopus rating (2007): SJR 1.301 SNIP 1.392
Scopus rating (2006): SJR 1.235 SNIP 1.543
Scopus rating (2005): SJR 1.088 SNIP 1.431
Scopus rating (2004): SJR 1.182 SNIP 1.556
Scopus rating (2003): SJR 1.456 SNIP 1.401
Scopus rating (2002): SJR 1.376 SNIP 1.35
Poisoning of Solid Oxide Electrolysis Cells by Impurities

Electrolysis of H2O, CO2, and co-electrolysis of H2O and CO2 was studied in Ni/yttria-stabilized zirconia (YSZ) electrode supported solid oxide electrolysis cells (SOECs) consisting of a Ni/YSZ support, a Ni/YSZ electrode layer, a YSZ electrolyte, and an lanthanum strontium manganite (LSM)/YSZ oxygen electrode. When applying the gases as received, the cells degraded significantly at the Ni/YSZ electrode, whereas only minor (and initial) degradation was observed for either the Ni/YSZ or LSM/YSZ electrode. Application of clean gases to the Ni/YSZ electrode resulted in operation without any long-term degradation, in fact some cells activated slightly. This shows that the durability of these SOECs is heavily influenced by impurities in the inlet gases. Cleaning the inlet gases to the Ni/YSZ electrode may be a solution for operating these Ni/YSZ-based SOECs without long-term degradation.
Solid Oxide Electrolysis Cells: Degradation at High Current Densities

The degradation of Ni/yttria-stabilized zirconia (YSZ)-based solid oxide electrolysis cells operated at high current densities was studied. The degradation was examined at 850°C, at current densities of −1.0, −1.5, and −2.0 A/cm², with a 50:50 (H₂O:H₂) gas supplied to the Ni/YSZ hydrogen electrode and oxygen supplied to the lanthanum, strontium manganite (LSM)/YSZ oxygen electrode. Electrode polarization resistance degradation is not directly related to the applied current density but rather a consequence of adsorbed impurities in the Ni/YSZ hydrogen electrode. However, the ohmic resistance degradation increases with applied current density. The ohmic resistance degradation is attributed to oxygen formation in the YSZ electrolyte grain boundaries near the oxygen electrode/electrolyte interface. ©2010 The Electrochemical Society
Advanced Test Method of Solid Oxide Cells in a Plug-Flow Setup

This paper describes a case study of two electrolysis tests of solid oxide cells [Ni/yttria-stabilized zirconia (YSZ)-YSZ-lanthanum strontium manganite (LSM)/YSZ] tested in a plug-flow setup. An extensively instrumented cell test setup was used, and the tests involved measurements of the cell impedance at open-circuit voltage and under current load, the cell voltage, and the in-plane voltage in the electrodes. From the cell-voltage measurements it was evident that a significant passivation of the cells occurred over the first similar to 10 days. Thereafter, the cells reactivated at constant electrolysis conditions. From measurements of the in-plane voltages in the electrodes and impedance spectra obtained during the electrolysis operation, we derive information about the resistance distributions in the Ni electrodes and describe how these distributions evolve over time. Impedance spectra at open-circuit voltage before and after electrolysis testing at various gas compositions were used to show that the Ni electrode was affected by the electrolysis operation, whereas the LSM electrode was not.

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
Authors: Jensen, S. H. (Intern), Hauch, A. (Intern), Hendriksen, P. V. (Intern), Mogensen, M. B. (Intern)
Pages: B757-B764
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Electrochemical Society. Journal
Volume: 156
Issue number: 6
ISSN (Print): 0013-4651
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.134 SNIP 0.867
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.037 SNIP 1
BFI (2014): BFI-level 1
Solid Oxide Electrolysis Cells: Performance and Durability

General information
State: Published
Authors: Hauch, A. (Intern), Bilde-Sørensen, J. (Intern), Mogensen, M. B. (Intern), Jacobsen, T. (Intern)
Number of pages: 165
Publication date: Jan 2008

Publication information
ISBN (Print): 978-87-550-3641-3
Original language: English
Series: Risø-PhD
Number: 37(EN)
Main Research Area: Technical/natural sciences
Electrolysis of steam and CO2

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Mogensen, M. B. (Intern), Jensen, S. H. (Intern), Ebbesen, S. (Intern), Hauch, A. (Intern)
Publication date: 2008
Event: Paper presented at Electroceramics XI, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences

FIB/TEM investigation of Si accumulation in the active layer of SOECs

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Soltmann, C. (Ekstern), Wiedenmann, D. (Ekstern), Hauch, A. (Intern), Vogt, U. (Ekstern), Mogensen, M. B. (Intern)
Publication date: 2008

Host publication information
Title of host publication: Proceedings (on CD-ROM)
Publisher: European solid oxide fuel cell forum
Main Research Area: Technical/natural sciences
Conference: 8th European Solid Oxide Fuel Cell Forum, Lucerne, Switzerland, 30/06/2008 - 30/06/2008
Source: orbit
Source-ID: 231635
Publication: Research › Article in proceedings – Annual report year: 2008

Fremtidens energiforsyning

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Experimental Surface and Nanomaterials Physics, Department of Physics, Theoretical Atomic-scale Physics, Center for Nanoteknologi
Pages: 63-79
Publication date: 2008

Host publication information
Title of host publication: Nanoteknologiske horisonter
Place of publication: Lyngby
Publisher: Danmarks Tekniske Universitet (DTU)
Editor: Hansen, A.
Main Research Area: Technical/natural sciences
Source: orbit
Highly efficient high temperature electrolysis

High temperature electrolysis of water and steam may provide an efficient, cost effective and environmentally friendly production of H-2. Using electricity produced from sustainable, non-fossil energy sources. To achieve cost competitive electrolysis cells that are both high performing i.e. minimum internal resistance of the cell, and long-term stable, it is critical to develop electrode materials that are optimal for steam electrolysis. In this article electrolysis cells for electrolysis of water or steam at temperatures above 200 degrees C for production of H-2 are reviewed. High temperature electrolysis is favourable from a thermodynamic point of view, because a part of the required energy can be supplied as thermal heat, and the activation barrier is lowered increasing the H-2 production rate. Only two types of cells operating at high temperature (above 200 degrees C) have been described in the literature, namely alkaline electrolysis cells (AEC) and solid oxide electrolysis cells (SOEC). In the present review emphasis is on state-of-the art electrode materials and development of new materials for SOECs. Based on the state-of-the-art performance for SOECs H-2 production by high temperature steam electrolysis using SOECs is competitive to H-2 production from fossil fuels at electricity prices below 0.02-0.03 is an element of per kWh. Though promising SOEC results on H-2 production have been reported a substantial R&D is still required to obtain inexpensive, high performing and long-term stable electrolysis cells.

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern), Ebbesen, S. (Intern), Jensen, S. H. (Intern), Mogensen, M. B. (Intern)
Pages: 2331-2340
Publication date: 2008
Main Research Area: Technical/natural sciences

Nanoscale chemical analysis and imaging of solid oxide cells
The performance of solid oxide cells (SOCs) is highly dependent on triple phase boundaries (TPBs). Therefore, detailed TPB characterization is crucial for their further development. We demonstrate that it is possible to prepare a similar to 50 nm thick transmission electron microscopy (TEM) lamella of the interface between the dense ceramic electrolyte and the porous metallic/ceramic hydrogen electrode of an SOC using focused ion beam milling. We show combined TEM/scanning TEM/energy-dispersive spectroscopy investigations of the nanostructure at the TPBs in a high-performance SOC. The chemical composition of nanoscale impurity phases at the TPBs has been obtained with a few nanometers lateral resolution. (c) 2008 The Electrochemical Society.

General information
State: Published
Solid Oxide Electrolysis Cells: Microstructure and Degradation of the Ni/Yttria-Stabilized Zirconia Electrode

Solid oxide fuel cells produced at Risø DTU have been tested as solid oxide electrolysis cells for steam electrolysis by applying an external voltage. Varying the sealing on the hydrogen electrode side of the setup verifies that the previously reported passivation over the first few hundred hours of electrolysis testing was an effect of the applied glass sealing. Degradation of the cells during long-term galvanostatic electrolysis testing [850°C, −1/2 A/cm², p(H₂O)/p(H₂)=0.5/0.5] was analyzed by impedance spectroscopy and the degradation was found mainly to be caused by increasing polarization resistance associated with the hydrogen electrode. A cell voltage degradation of 2%/1000 h was obtained. Postmortem analysis of cells tested at these conditions showed that the electrode microstructure could withstand at least 1300 h of electrolysis testing, however, impurities were found in the hydrogen electrode of tested solid oxide electrolysis cells. Electrolysis testing at high current density, high temperature, and a high partial pressure of steam [−2 A/cm², 950°C, p(H₂O)=0.9 atm] was observed to lead to significant microstructural changes at the hydrogen electrode-electrolyte interface.

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern), Ebbesen, S. (Intern), Jensen, S. H. (Intern), Mogensen, M. B. (Intern)
Pages: B1184-B1193
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of the Electrochemical Society
Volume: 155
Issue number: 11
ISSN (Print): 0013-4651
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.134 SNIP 0.867
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.037 SNIP 1
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.147 SNIP 1.206
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.151 SNIP 1.299
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.329 SNIP 1.296
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.33 SNIP 1.345
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.417 SNIP 1.312
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.45 SNIP 1.267
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.608 SNIP 1.416
Scopus rating (2007): SJR 1.58 SNIP 1.325
Scopus rating (2006): SJR 1.611 SNIP 1.54
Scopus rating (2005): SJR 1.519 SNIP 1.484
Scopus rating (2004): SJR 1.719 SNIP 1.706
Scopus rating (2003): SJR 1.962 SNIP 1.679
Scopus rating (2002): SJR 2.147 SNIP 1.646
Scopus rating (2001): SJR 1.651 SNIP 1.738
A method to separate process contributions in impedance spectra by variation of test conditions

Many processes contribute to the overall impedance of an electrochemical cell, and these may be difficult to separate in the impedance spectrum. Here, we present an investigation of a solid oxide fuel cell based on differences in impedance spectra due to a change of operating parameters and present the result as the derivative of the impedance with respect to ln(f). The method is used to separate the anode and cathode contributions and to identify various types of processes.

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Physical Chemistry, Department of Chemistry
Authors: Jensen, S. H. (Intern), Hauch, A. (Intern), Hendriksen, P. V. (Intern), Mogensen, M. B. (Intern), Bonanos, N. (Intern), Jacobsen, T. (Intern)
Pages: B1325-B1330
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Electrochemical Society. Journal
Volume: 154
Issue number: 12
ISSN (Print): 0013-4651
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.134 SNIP 0.867
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.037 SNIP 1
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.147 SNIP 1.206
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.151 SNIP 1.299
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.329 SNIP 1.296
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.33 SNIP 1.345
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.417 SNIP 1.312
BFI (2009): BFI-level 1
Durability of solid oxide electrolysis cells for hydrogen production

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Authors: Hauch, A. (Intern), Jensen, S. H. (Intern), Ebbesen, S. (Intern), Mogensen, M. B. (Intern)
Pages: 327-338
Publication date: 2007

Host publication information
Title of host publication: Energy solutions for sustainable development. Proceedings
Publisher: Risø National Laboratory
Editors: Sønderberg Petersen, L., Larsen, H.
ISBN (Print): 978-87-550-3603-1

Series: Denmark. Forskningscenter Risoe. Risoe-R
Number: 1608(EN)
ISSN: 0106-2840
Main Research Area: Technical/natural sciences
Conference: Risø international energy conference 2007, Risø (DK), 01/01/2007
Risø-R-1608, Risø-R-1608(EN)
Electronic versions:
ris_r_1608.pdf
Source: orbit
Source-ID: 216410
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

EM investigations of impurities in a fuel cell H2 electrode

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
How to transfer spectra from the INCA software to spectra that can be used in the NoranSystemSix software

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern)
Publication date: 2007
Event: Paper presented at Thermo Fisher scientific microanalysis Nordic users meeting, Risø, Denmark.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 216673
Publication: Research › Paper – Annual report year: 2007

Nanoscale chemical analysis and imaging of solid oxide cells

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern)
Publication date: 2007
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 216095
Publication: Research › Paper – Annual report year: 2007

Reversible solid oxide cells

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Authors: Mogensen, M. B. (Intern), Jensen, S. (Intern), Hauch, A. (Intern), Chorkendorff, I. (Ekstern), Jacobsen, T. (Ekstern)
Publication date: 2007
Event: Paper presented at 32. International Cocoa Beach conference and exposition on advanced ceramics and composites, Cocoa Beach, FL (US), .
Main Research Area: Technical/natural sciences
Links:
Source: orbit
Source-ID: 216358
Publication: Research › Paper – Annual report year: 2007

Reversible Solid Oxide Cells: Performance of Reversible Solid Oxide Cells: 301-MogensenPerformance of Reversible Solid Oxide Cells: A Review

General information
State: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Experimental Surface and Nanomaterials Physics, Department of Physics, Department of Chemistry
Silica segregation in the Ni/YSZ electrode

Solid oxide fuel cells were tested as solid oxide electrolysis cells used for high-temperature steam electrolysis. The cells were tested at a variety of operation temperatures, current densities, and gas flows to the electrodes. The cell voltages monitored during the electrolysis operation increased significantly during the first few days of testing. Impedance spectroscopy obtained during electrolysis shows that it is the Ni/yttria-stabilized zirconia (YSZ) electrode that passivates. Reference cells and tested cells were examined in a scanning electron microscope after testing. These postmortem analyses reveal the reason for the observed passivation, because results from energy-dispersive spectroscopy clearly show evidence that silica-containing impurities have segregated to the hydrogen electrode/electrolyte interface during electrolysis testing. Examples of different microstructures and amounts of Si-containing impurities in the electrolyte/hydrogen electrode interface are presented and related to the electrolysis test conditions and the passivation histories of the electrolysis cells. (C) 2007 The Electrochemical Society.
Solid oxide electrolysis for fuel production

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Authors: Ebbesen, S. (Intern), Hauch, A. (Intern), Jensen, S. (Intern), Mogensen, M. B. (Intern)
Publication date: 2007
Event: Abstract from Risø international energy conference 2007, Risø (DK),
Main Research Area: Technical/natural sciences
Links:
http://www.risoe.dk/rispubl/reports/ris-r-1608_presentations.pdf
Source: orbit
Source-ID: 216424
Publication: Research - peer-review › Journal article – Annual report year: 2007

Performance and durability of solid oxide electrolysis cells
Solid oxide fuel cells produced at Risø National Laboratory have been tested as electrolysis cells by applying an external voltage. Results on initial performance and durability of such reversible solid oxide cells at temperatures from 750 to 950 degrees C and current densities from -0.25 A/cm(2) to -0.50 A/cm(2) are reported. The full cells have an initial area specific resistance as low as 0.27 Ω cm(2) for electrolysis operation at 850 degrees C. During galvanostatic long-term electrolysis tests, the cells were observed to passivate mainly during the first similar to 100 h of electrolysis. Cells that have been passivated during electrolysis tests can be partly activated again by operation in fuel cell mode or even at constant electrolysis conditions after several hundred hours of testing.

General information
State: Published
Organisations: Department of Chemistry, Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Authors: Hauch, A. (Intern), Jensen, S. H. (Intern), Ramousse, S. (Intern), Mogensen, M. B. (Intern)
Pages: A1741-A1747
Publication date: 2006
Performance of reversible solid oxide cells: A review
Proton Diffusion in the Ni/YSZ Electrode of a Solid Oxide Cell

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy, Department of Physics, Department of Chemistry, Technical University of Denmark
Authors: Jensen, S. (Ekstern), Hauch, A. (Intern), Chorkendorff, I. (Intern), Jacobsen, T. (Intern), Mogensen, M. B. (Intern)
Pages: Abstract 843
Publication date: 2006
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 264212
Publication: Research - peer-review › Conference abstract in journal – Annual report year: 2006

The potential of the solid oxide electrolyser for the production of synthetic fuels

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy
Authors: Jensen, S. (Ekstern), Hauch, A. (Intern), Mogensen, M. B. (Intern)
Event: Abstract from Hypothesis 6, Havana (CU), 8-12 May, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 309458
Publication: Research › Conference abstract for conference – Annual report year: 2006

Electrode stability in high temperature electrolysis of steam

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern), Jensen, S. (Ekstern), Mogensen, M. B. (Intern)
Ni/YSZ-electrode passivation at cathodic current

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy
Authors: Jensen, S. H. (Intern), Hauch, A. (Intern), Mogensen, M. B. (Intern)
Pages: 247-252
Publication date: 2005

Host publication information
Title of host publication: Solid state electrochemistry. Proceedings
Place of publication: Roskilde
Publisher: Risø National Laboratory
ISBN (Print): 87-550-3455-1
Main Research Area: Technical/natural sciences
Source-ID: 308425
Publication: Research › Conference abstract for conference – Annual report year: 2005

Ni/YSZ electrodes in solid oxide electrolyser cells

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern), Jensen, S. H. (Intern), Mogensen, M. B. (Intern)
Pages: 203-208
Publication date: 2005

Host publication information
Title of host publication: Solid state electrochemistry. Proceedings
Place of publication: Roskilde
Publisher: Risø National Laboratory
ISBN (Print): 87-550-3455-1
Main Research Area: Technical/natural sciences
Source-ID: 308383
Publication: Research › Article in proceedings – Annual report year: 2005

Stability of solid oxide electrolyser cells

General information
State: Published
Organisations: Risø National Laboratory for Sustainable Energy
Authors: Hauch, A. (Intern), Jensen, S. (Ekstern), Menon, M. (Intern), Mogensen, M. B. (Intern)
Pages: 216-230
Publication date: 2005

Host publication information
Title of host publication: Technologies for sustainable energy development in the long term. Proceedings
Editors: Sønderberg Petersen, L., Larsen, H.
2H chemical shift anisotropies from high-field 2H MAS NMR spectroscopy
2H chemical shift anisotropies (CSAs) have been determined for the first time for polycrystalline samples employing 2H MAS NMR spectroscopy at high magnetic field strength (14.1 T). The 2H CSA is reflected as distinct asymmetries in the manifold of spinning sidebands (ssbs) observed for the two overlapping single-quantum transitions. Least-squares fitting to the manifold of ssbs allows determination of the 2H CSA parameters along with the quadrupole coupling parameters. This is demonstrated for KD2PO4, ND4D2PO4, KDSO4, KDCO3, α-(COOD)2, α-(COOD)2 · 2D2O, and boehmite (AlOOD) which exhibit 2H shift anisotropies in the range 13 ≤ δσ ≤ 27 ppm. For fixed values of the shift anisotropy and the 2H quadrupole coupling it is shown that the precision of the CSA parameters depends strongly on the asymmetry parameter (ηQ) for the quadrupole coupling tensor, giving the highest precision for ηQ ≈ 0. The 2H CSA parameters (δσ and ησ) are in good agreement with 1H CSA data reported in the literature for the corresponding protonated samples from 1H NMR spectra employing various homonuclear decoupling techniques. The determination of 2H quadrupole coupling parameters and 2H (1H) CSAs from the same 2H MAS NMR experiment may be particularly useful in studies of hydrogen bonding since the 2H quadrupole coupling constant and the CSA appear to characterize bond lengths in a hydrogen bond in a different manner. © 2003 Elsevier Inc. All rights reserved.
Scopus rating (2009): SJR 1.608 SNIP 1.127
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.474 SNIP 1.063
Scopus rating (2007): SJR 1.358 SNIP 1.079
Scopus rating (2006): SJR 1.382 SNIP 1.05
Scopus rating (2005): SJR 1.287 SNIP 1.133
Scopus rating (2004): SJR 1.281 SNIP 1.136
Scopus rating (2003): SJR 1.219 SNIP 1.067
Scopus rating (2002): SJR 1.234 SNIP 0.97
Scopus rating (2001): SJR 1.381 SNIP 1.003
Scopus rating (2000): SJR 1.363 SNIP 1.03
Scopus rating (1999): SJR 1.156 SNIP 1.056

Original language: English
DOIs:
10.1016/j.jmr.2003.09.007
Source: dtu
Source-ID: u::10647
Publication: Research - peer-review › Journal article – Annual report year: 2003

Projects:

Modeling of degradation processes in high temperature electrolysis cells
Department of Energy Conversion and Storage
Period: 01/09/2016 → 31/08/2019
Number of participants: 4
Phd Student:
Trini, Martina (Intern)
Supervisor:
Hauch, Anne (Intern)
Hendriksen, Peter Vang (Intern)
Main Supervisor:
Chen, Ming (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Development and pressure testing of solid oxide electrolyser cells
Department of Energy Conversion and Storage
Period: 01/07/2016 → 30/09/2016
Number of participants: 4
Phd Student:
Gao, Ying (Intern)
Supervisor:
Graves, Christopher R. (Intern)
Hauch, Anne (Intern)
Main Supervisor:
Jensen, Søren Højgaard (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD
SOFC degradation studies
Department of Energy Conversion and Storage
Period: 15/08/2015 → 14/08/2018
Number of participants: 3
Phd Student:
Ploner, Alexandra (Intern)
Supervisor:
Hauch, Anne (Intern)
Main Supervisor:
Hagen, Anke (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Lifetime limiting effects in pre-commercial solid cell devices
Department of Energy Conversion and Storage
Period: 01/03/2014 → 21/06/2017
Number of participants: 7
Phd Student:
Skafte, Theis Løye (Intern)
Supervisor:
Blennow Tullmar, Peter (Intern)
Graves, Christopher R. (Intern)
Main Supervisor:
Hjelm, Johan (Intern)
Examiner:
Hauch, Anne (Intern)
Lanzini, Andrea (Ekstern)
Weber, André (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD
Project: PhD

Elektrode Kinetics and Gas Conversion in Solid Oxide Cells
Department of Energy Conversion and Storage
Period: 01/01/2014 → 20/04/2016
Number of participants: 7
Phd Student:
Njodzefon, Jean-Claude (Intern)
Supervisor:
Graves, Christopher R. (Intern)
Weber, André (Ekstern)
Main Supervisor:
Hjelm, Johan (Intern)
Examiner:
Hauch, Anne (Intern)
Krügel, Albert (Ekstern)
Schefold, Josef (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed

Relations
Publications:
Electrode Kinetics and Gas Conversion in Solid Oxide Cells
Project: PhD

**In-situ Neutron Imaging of Solid Oxide Fuel Cells**
Department of Energy Conversion and Storage
Period: 01/01/2013 → 20/04/2016
Number of participants: 7
Phd Student:
Makowska, Małgorzata Grazyna (Intern)
Supervisor:
Lauridsen, Erik Mejdal (Intern)
Strobl, Markus (Ekstern)
Main Supervisor:
Kuhn, Luise Theil (Intern)
Examiner:
Hauch, Anne (Intern)
Grünzweig, Christian (Ekstern)
Hall, Stephen A. (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

**Forbedring af Materialer til fast Oxid Brændseisceller**
Department of Chemistry
Period: 15/08/2004 → 28/01/2008
Number of participants: 7
Phd Student:
Hauch, Anne (Intern)
Supervisor:
Bilde-Sørensen, Jørgen (Intern)
Mogensen, Mogens Bjerg (Intern)
Main Supervisor:
Jacobsen, Torben (Intern)
Examiner:
Skaarup, Steen (Intern)
Falk, Lena K. L. (Ekstern)
Holtappels, Peter (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Risø (Løn)
Project: PhD

**Activities:**

**The 66th Annual Meeting of the International Society of Electrochemistry**
Anne Hauch (Participant)
Department of Energy Conversion and Storage
Applied Electrochemistry

**Description**
International Society of Electrochemistry 66th annual meeting
Related event

**The 66th Annual Meeting of the International Society of Electrochemistry**

04/10/2015 → 09/10/2015
Taipei, Taiwan, Province of China

Activity: Participating in or organising an event › Participating in or organising workshops, courses, seminars etc.

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**Er der vedvarende energi nok til os alle?**

Period: 21 Sep 2015 → 25 Sep 2015

Anne Hauch (Lecturer)

Department of Energy Conversion and Storage

Applied Electrochemistry

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**Dansk Naturvidenskabsfestival 2015**

21/09/2015 → 25/09/2015

Denmark

Activity: Talks and presentations › Conference presentations

---

**Vedvarende energi: Ny teknologi, der ændrer vores hverdag**

Period: 20 May 2015

Anne Hauch (Lecturer)

Department of Energy Conversion and Storage

Applied Electrochemistry

**Description**

Foredrag om vedvarende energi og energikonvertering og lagring i forelæsningsserie om "Ny teknologi" på Aarhus Folkeuniversitet (Emdrup afd.)

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**Unknown external organisation**

Activity: Talks and presentations › Conference presentations

---

**Energiforbrug - Brændselceller og brint: Vedvarende Energi**

Period: 10 Feb 2015

Anne Hauch (Lecturer)

Department of Energy Conversion and Storage

Applied Electrochemistry

**Description**

Forelæsning om brændselceller og bring i forelæsningsserien "Vedvarende Energi" på Aarhus Folkeuniversitet (Emdrup afdeling)

---

**Related external organisation**

**Unknown external organisation**

Activity: Talks and presentations › Conference presentations

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**Er der vedvarende energi nok til os alle?: Om brændselceller og elektrolyseceller til effektiv energikonvertering**

Period: 26 Sep 2014

Anne Hauch (Lecturer)

Department of Energy Conversion and Storage

Applied Electrochemistry

**Description**
Foredrag i forbindelse med Dansk Naturvidenskabsfestival

Inviteret foredrag
Documents:
Brændselsceller_og_elektrolyseceller_DanskNaturvidenskabsfestival_AnneHauch_Sepetember26th2014

Related event

Dansk Naturvidenskabsfestival
26/09/2014 → …
Lyngby, Denmark
Activity: Talks and presentations › Conference presentations

European fuel cell 2014 - 11th European SOFC and SOE Forum 2014
Period: 1 Jul 2014 → 4 Jul 2014
Anne Hauch (Speaker)
Department of Energy Conversion and Storage
Applied Electrochemistry

Description
"Ni/YSZ microstructure optimization for long-term stability of solid oxide electrolysis cells" (presentation)

European fuel cell 2014 - 11th European SOFC and SOE Forum 2014
01/07/2014 → 04/07/2014
Lucerne, Switzerland
Activity: Talks and presentations › Conference presentations

13th International Symposium on Solid Oxide Fuel Cells (SOFC-XIII)
Anne Hauch (Participant)
Applied Electrochemistry
Department of Energy Conversion and Storage

Description
Participation in and oral presentation at the 13th International Symposium on Solid Oxide Fuel cells (SOFC-XIII)
Sulfur Poisoning of Ni/stabilized-zirconia Anodes – Effect on Long-Term Durability

13th International Symposium on Solid Oxide Fuel Cells (SOFC-XIII)
06/10/2013 → 11/10/2013
Okinawa, Japan
Activity: Participating in or organising an event › Participating in or organising workshops, courses, seminars etc.

European Fuel Cell Forum 2012
Period: 30 Jun 2012 → 3 Jul 2012
Anne Hauch (Participant)
Applied Electrochemistry
Department of Energy Conversion and Storage

Description
Deltager samt poster bidrag
Multilayer Tape Cast SOFC - Effect of Anode Sintering Temperature
Documents:
EFCF_poster_cbir_2012-06-22_hauc_edit_FINAL
Related event

**European Fuel Cell Forum 2012**

27/06/2012 → 29/06/2012
Luzern, Switzerland

Activity: Participating in or organising an event › Participating in or organising workshops, courses, seminars etc.

**Studienævn DTU Energi (External organisation)**

Period: 1 Jan 2012 → 31 Dec 2015
Anne Hauch (Chairman)

Department of Energy Conversion and Storage
Applied Electrochemistry

**Description**

Formand for DTU Energis studienævn

Body type: Institutstudienævn

**Related external organisation**

**Studienævn DTU Energi**

Activity: Membership › Membership in committee, council, board

**UDTU Education in University Teaching at DTU**

Anne Hauch (Participant)

Department of Energy Conversion and Storage
Applied Electrochemistry

**Description**

Participation in module 1-4 (all modules) in UDTU Education in University Teaching at DTU

UDTU - university teachers education

**Related event**

**UDTU Education in University Teaching at DTU**

02/08/2010 → 30/06/2011
Lyngby, Denmark

Activity: Participating in or organising an event › Participating in or organising workshops, courses, seminars etc.