A combined SEM and CV Study of Solid Oxide Fuel Cell Interconnect Steels

Scanning electron microscopy and cyclic voltammetry were used to investigate the high temperature oxidation behavior of two solid oxide fuel cell interconnect steels. One alloy had a low content of manganese; the other alloy had a high content of manganese. Four reduction and four oxidation peaks were observed in the voltammograms of the low manganese alloy at a temperature of 800 oC. The voltammograms of the alloy with a high content of manganese were different. At 600 oC three reduction peaks and two oxidation peaks were observed. At 800 oC additional peaks were observed in the voltammogram for this alloy.

Electrochemical testing of composite electrodes of (La1−xSr x )0.99MnO3 and doped ceria in NO-containing atmosphere

The possibility of using electrochemical cells for removal of NO x from an exhaust gas with excess O2 has been examined. (La1−xSr x )0.99MnO3 (LSM) and ceria doped with Pr or Gd were selected as electrode materials and investigated in three-electrode cells. The electrodes were characterised electrochemically with electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV), and the gas composition monitored while the electrodes were polarised. The electrodes of (La0.5Sr0.5)0.99MnO3 (LSM50) and Ce0.8Pr0.2O2−δ exhibit higher current densities in 0.1% NO in Ar than in air at 300 to 400 °C during CV. This indicates some apparent selectivity towards NO compared to O2. The electrodes can remove NO, when polarised to at least −0.6 V vs. Pt/Air at 600 °C, and EIS measurements under polarisation indicate that the kinetics of the electrodes change, when the electrode potential gets below −0.6 V vs. Pt/Air.
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.

General information

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Pore former induced porosity in LSM/CGO cathodes for electrochemical cells for flue gas purification

In this study the effect of the characteristics of polymethyl methacrylate (PMMA) pore formers on the porosity, pore size distribution and the air flow through the prepared lanthanum strontium manganate/gadolinium-doped cerium oxide (LSM/CGO) cathodes was investigated. Porous cathodes were obtained and the highest porosity measured was 46.4% with an average pore diameter of 0.98 μm. The air flow through this cathode was measured to 5.8 ml/(min mm2). Also the effect of exposure time to the solvent was tested for the most promising PMMA pore former and it was found that the
average pore diameter decreases as a result of elongated exposure. Also, prolong milling of the LSM powder was found to decrease the porosity of the final cathode and milling time should be highly controlled in order to obtain as porous cathodes as possible.

The effect of loading and particle size on the oxygen reaction in CGO impregnated Pt electrodes
Porous platinum electrodes impregnated with Gd x Ce1−x O2−δ (CGO) are investigated to characterise how nano-sized CGO grains affect the oxygen reaction. Impedance measurements were performed at temperatures between 450 and 750 °C and at oxygen partial pressures of 0.2 and 5 × 10−5 bar for electrodes with various CGO loadings and electrodes annealed at various temperatures. The morphology was characterised by scanning electron microscopy and the CGO grain size was determined from X-ray diffraction peak broadening. The results showed that the polarisation resistance decreased with increasing CGO loading and increasing annealing temperature. CGO facilitates transport of oxygen ions thereby increasing the effective triple-phase boundary.
Co-electrolysis of CO₂ and H₂O in solid oxide cells: Performance and durability
This study examines the initial performance and durability of a solid oxide cell applied for co-electrolysis of CO₂ and H₂O. Such a cell, when powered by renewable/nuclear energy, could be used to recycle CO₂ into sustainable hydrocarbon fuels. Polarization curves and electrochemical impedance spectroscopy were employed to characterize the initial performance and to break down the cell resistance into the resistance for the specific processes occurring during operation. Transformation of the impedance data to the distribution of relaxation times (DRT) and comparison of measurements taken under systematically varied test conditions enabled clear visual identification of five electrode processes that contribute to the cell resistance. The processes could be assigned to each electrode and to gas concentration effects by examining their dependence on gas composition changes and temperature. This study also introduces the use of the DRT to study cell degradation without relying on a model. The durability was tested at consecutively higher current densities (and corresponding overpotentials). By analyzing the impedance spectra before and after each segment, it was found that at low current density operation (~ 0.25 A/cm² segment) degradation at the Ni/YSZ electrode was dominant, whereas at higher current densities (~ 0.5 A/cm² and ~ 1.0 A/cm²), the Ni/YSZ electrode continued to degrade but the serial resistance and degradation at the LSM/YSZ electrode began to also play a major role in the total loss in cell performance. This suggests different degradation mechanisms for high and low current density operation.
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.

Durability of solid oxide fuel cells using sulfur containing fuels

The usability of hydrogen and also carbon containing fuels is one of the important advantages of solid oxide fuel cells (SOFCs), which opens the possibility to use fuels derived from conventional sources such as natural gas and from renewable sources such as biogas. Impurities like sulfur compounds are critical in this respect. State-of-the-art Ni/YSZ SOFC anodes suffer from being rather sensitive towards sulfur impurities. In the current study, anode supported SOFCs with Ni/YSZ or Ni/ScYSZ anodes were exposed to H2S in the ppm range both for short periods of 24h and for a few hundred hours. In a fuel containing significant shares of methane, the reforming activities of the Ni/YSZ and Ni/ScYSZ anodes were severely poisoned already at low H2S concentrations of ~2ppm H2S. The poisoning effect on the cell voltage was reversible only to a certain degree after exposure of 500h in the state-of-the-art cell, due to a loss of percolation of Ni particles in the Ni/YSZ anode layers closest to the electrolyte. Using SOFCs with Ni/ScYSZ anodes improved the H2S tolerance considerably, even at larger H2S concentrations of 10 and 20ppm over a few hundred hours.
Durable SOC stacks for production of hydrogen and synthesis gas by high temperature electrolysis

Electrolysis of steam and co-electrolysis of steam and carbon dioxide was studied in Solid Oxide Electrolysis Cell (SOEC) stacks composed of Ni/YSZ electrode supported SOECs. The results of this study show that long-term electrolysis is feasible without notable degradation in these SOEC stacks. The degradation of the electrolysis cells was found to be influenced by the adsorption of impurities from the applied inlet gases, whereas the application of chromium containing interconnect plates and glass sealings do not seem to influence the durability when operated at 850 °C. Cleaning the inlet gases to the Ni/YSZ electrode resulted in operation without long-term degradation, and may therefore be a solution for operating these Ni/YSZ based SOEC stacks without degradation.

Electrical conductivity measurements of aqueous and immobilized potassium hydroxide

Electrolysis of steam and co-electrolysis of steam and carbon dioxide was studied in Solid Oxide Electrolysis Cell (SOEC) stacks composed of Ni/YSZ electrode supported SOECs. The results of this study show that long-term electrolysis is feasible without notable degradation in these SOEC stacks. The degradation of the electrolysis cells was found to be influenced by the adsorption of impurities from the applied inlet gases, whereas the application of chromium containing interconnect plates and glass sealings do not seem to influence the durability when operated at 850 °C. Cleaning the inlet gases to the Ni/YSZ electrode resulted in operation without long-term degradation, and may therefore be a solution for operating these Ni/YSZ based SOEC stacks without degradation.

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Electrical conductivity measurements of aqueous and immobilized potassium hydroxide
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Electrical conductivity of Ni–YSZ composites: Degradation due to Ni particle growth

The short-term changes in the electrical conductivity of Ni–YSZ composites (cermets) suitable for use in Solid Oxide Fuel Cells (SOFC) were measured by an in-situ 4-point DC technique. The isothermal reduction was carried out in dry, humidified or wet hydrogen at temperatures from 600 to 1000°C. While the cermets reduced at 600°C showed a stable conductivity of 1000–1200 S/cm, rapid initial conductivity loss was observed at elevated temperatures. At 1000°C the conductivity degraded nearly instantaneously to about 800 S/cm, and continued to decline fast to about 400 S/cm. At 850°C, the presence of steam did have an accelerating effect on the conductivity loss. Scanning Electron Microscopy of cermets reduced in different conditions showed increasing particle size and loss of metal-to-metal percolation in the samples reduced at higher temperatures. The short-term changes in conductivity were modelled using two different semi-empirical approaches. Thermodynamic calculations were carried out to assess the vapourisation of Ni in the conditions tested. The rate and mechanisms of conductivity degradation due to Ni particle growth are discussed in light of the measurements, modelling and literature data.

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 Sr0.9Ti0.9Nb0.10O3–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.
Electrochemical removal of segregated silicon dioxide impurities from yttria stabilized zirconia surfaces at elevated temperatures

Here we report on the electrochemical removal of segregated silicon dioxide impurities from Yttria Stabilized Zirconia (YSZ) surfaces at elevated temperatures studied under Ultra High Vacuum (UHV) conditions. YSZ single crystals were heated in vacuum by an applied 18kHz a.c. voltage using the ionic conductivity of YSZ. The crystals were annealed in vacuum and atmospheres of water or oxygen from 10−5 mbar to 100mbar in the temperature range of 1100°C to 1275°C. The surface was after annealing analyzed by X-ray Photoelectron Spectroscopy (XPS) without exposing the crystal to atmosphere between annealing and XPS analysis. Silicon enrichment of the surface was only observed at oxygen and water vapor partial pressures above 25mbar and 10mbar, respectively. No silicon was observed on crystals annealed in vacuum and at oxygen or water vapor partial pressures below 10mbar. The YSZ seems to get partially electrochemically reduced by the a.c. voltage when no oxidation substances are present. The absence of silicon on the surfaces annealed in vacuum or at low oxygen or water vapor partial pressures was attributed to electrochemical reduction of silicon dioxide to volatile silicon monoxide on the YSZ surface. This was demonstrated by silicon enrichment of a gold foil placed behind the YSZ crystal surface while annealed. The results suggest a fast way to clean YSZ for trace silicon dioxide impurities found in the bulk of the cleanest crystals commercially available.
Electrochemical Routes towards Sustainable Hydrocarbon Fuels

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**Electrolysis for Integration of Renewable Electricity and Routes towards Sustainable Fuels**

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Electronic conductivity of Ce(0.9)Gd(0.1)O(1.95-δ) and Ce(0.8)Pr(0.2)O(2-δ): Hebb-Wagner polarisation in the case of redox active dopants and interference.

The electronic conductivity of Ce(0.9)Gd(0.1)O(1.95-δ) and Ce(0.8)Pr(0.2)O(2-δ) under suppressed ionic flow was measured as a function of pO(2) in the range from 10³ atm to 10⁻¹⁷ atm for temperatures between 600 °C and 900 °C by means of Hebb-Wagner polarisation. The steady state I-V curve of Ce(0.9)Gd(0.1)O(1.95-δ) could be well described by the standard Hebb-Wagner equation [M. H. Hebb, J. Chem. Phys., 1952, 20, 185; C. Wagner, Z. Elektrochem., 1956, 60, 4], yielding expressions for the n- and p-type conductivity as a function of pO(2). On the other hand, significant deviation of the steady state I-V curve from the standard Hebb-Wagner equation was observed for the case of Ce(0.8)Pr(0.2)O(2-δ). It is shown that the I-V curve can be successfully reproduced when the presence of the redox active dopant, Pr(3+)/Pr(4+), is taken into account, whereas even better agreement can be reached when further taking into account the interference between the ionic and electronic flows [C. Chatzichristodoulou, W.-S. Park, H.-S. Kim, P. V. Hendriksen and H.-I. Yoo, Phys. Chem. Chem. Phys., 2010, 12, 33]. Expressions are deduced for the small polaron mobilities in the Ce 4f and Pr 4f bands of Ce(0.8)Pr(0.2)O(2-δ).

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Elektroder baseret på ceria og rustfrit stål: Ceria and stainless steel based electrodes

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Contributors: Blennow Tullmar, P., Mogensen, M. B.
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Evaluación de membranas ceria delgadas para reactores de gas sintético—Preparación, caracterización y prueba
Gadolinium doped ceria (Ce0.1Gd0.9O1.95−δ, CGO10) was investigated as oxygen separation membrane material for application in syngas production. Planar, thin film CGO10 membranes were fabricated by tape casting and lamination on porous NiO-YSZ supports and subsequent co-sintering. High oxygen fluxes, up to 16Nmlcm−2min−1 at 900°C, were obtained when placing the membrane between air and humidified hydrogen (H2/H2O=20). Initial experiments for syngas production were performed by testing the CGO10 membrane with methane and steam feed. The mechanical integrity of CGO10 membranes during operation (heat up, cooling, reduction and re-oxidation) was also investigated. Chemically induced stress in the CGO10 membrane due to harsh reduction of the CGO10 material at high temperatures and very low pO2 values can lead to mechanical failure by lattice expansion. Calculations of the oxygen non-stoichiometry profile in the 30μm thin CGO membrane under operation reveal that due to oxygen permeation in the membrane the largest non-stoichiometry at the permeate (fuel) side is more than a factor of 6 times smaller at 850°C than that expected for CGO10 at equilibrium. The related relative expansion of the thin film CGO membrane should therefore lie below the expansion limit of 0.1% expected to be critical for mechanical stability and thereby allows for operation at high temperatures and low oxygen partial pressures.

General information
High Performance Cathodes for Solid Oxide Fuel Cells Prepared by Infiltration of La0.6Sr0.4CoO3d into Gd-Doped Ceria

Cathodes prepared by infiltration of La0.6Sr0.4CoO3d (LSC40) into a porous Ce0.9Gd0.1O1.95 (CGO10) backbone have been developed for low temperature solid oxide fuel cells. The CGO10 backbone has been prepared by screen printing a CGO10 ink on both sides of a 180 μm dense CGO10 electrolyte-tape followed by firing. LSC40 was introduced into the CGO10 porous backbone by multiple infiltrations of aqueous nitrate solutions followed by firing at 350°C. A systematic study of the performance of the cathodes was performed by varying the CGO10 backbone firing temperature, the LSC40 firing temperature and the number of infiltrations. The cathode polarization resistance was measured using electrochemical impedance spectroscopy on symmetrical cells in ambient air, while the resulting structures were characterized by scanning electron microscopy (SEM) and high temperature X-ray diffraction (HT-XRD). The firing temperature of 600°C for the LSC40 infiltrate was found to provide a balance between LSC40 material formation and high surface area micro=nanostructure. The lowest polarization resistances measured at 600 and 400°C were 0.044 and 2.3 X cm² in air, respectively. During degradation tests at 600°C, the cathode polarization resistance levels out after about 450 h of testing, giving a final polarization resistance of 0.07 X cm². copyright 2011 The Electrochemical Society.

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Impedance measurements on Au microelectrodes using controlled atmosphere high temperature scanning probe microscope

High temperature impedance measurements on Au microelectrodes deposited on polished yttria stabilized zirconia (YSZ) pellets were demonstrated using a newly designed controlled atmosphere high temperature scanning probe microscope (CAHT-SPM). Probes based on Pt0.8Ir0.2 were fabricated and employed in all the investigations. The electrical properties of the Au microelectrodes were investigated using CAHT-SPM at various temperatures in air. The influences of the tip-sample force and of the size of the microelectrode on the electrical properties of the Au microelectrodes were also studied. The impedance spectra of circular Au microelectrodes down to 8μm in diameter at different temperatures were successfully obtained. The CAHT-SPM presented in this paper is capable of obtaining topography images, conductivity images and impedance spectra in-situ in a temperature range from room temperature to at least 650°C.

Impregnation of LSM Based Cathodes for Solid Oxide Fuel Cells

Composites cathodes consisting of strontium doped lanthanum manganite (LSM) and yttria stabilized zirconia have been impregnated with the nitrates corresponding to the nominal compositions: La0.75Sr0.25Mn1.05O3 +/-delta (LSM25), Ce0.8Sm0.2O2 (SDC) and a combination of both (dual). The latter performed best with a polarization resistance (R-P) of 0.39 Omega cm(2) at 600 degrees C and 0.039 Omega cm(2) at 750 degrees C compared to 2.17 and 0.19 Omega cm(2) respectively for electrodes without impregnation. Furthermore the dual impregnation decreased the activation energy of R-P to 1.19 eV compared to 1.35 eV for cells without impregnation. [DOI: 10.1016/j.ssi.2011.06.017] All rights reserved.
Improvement of LSM15-CGO10 electrodes for electrochemical removal of NOx by KNO3 and MnOx impregnation

LSM15-CGO10 (La0.85Sr0.15MnO3-Ce0.90Gd0.1O1.95) electrodes were impregnated with either KNO3 or MnOx, and the effect of the impregnations on the activity in NO containing atmospheres was investigated by electrochemical impedance spectroscopy and cyclic voltammetry. The electrodes were tested in 1000 ppm NO, 10% O2 and 1000 ppm NO + 10% O2 in the temperature range 300-500 °C and the electrodes were investigated by scanning electron microscopy before and after testing. At 400-450 °C a NOx-storage process was observed on the KNO3-impregnated electrodes, this process appeared to be dependent on preceding catalytically formation of NO2. Despite a marked difference in the microstructure of the impregnated KNO3 and MnOx, both impregnations caused a significant reduction in the polarization resistance of the electrodes, due to a general decrease in resistance of all the identified electrode processes. The effect of the impregnation was strongest at low temperatures, likely because the microstructure of the impregnated compounds changed at higher temperatures. Scanning electron microscopy images revealed a significant change in the microstructure of the impregnated samples after the test.

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Impurity features in Ni-YSZ-H₂-H₂O electrodes

The impurity content of previously electrochemically characterized patterned Ni anodes for SOFC (solid oxide fuel cells) has been analyzed with a combination of SEM (scanning electron microscopy), AFM (atomic force microscopy), XPS (X-ray photoelectron spectroscopy) and TOF-SIMS (time-of-flight secondary ion mass spectrometry). This analysis yields comprehensive information on composition and lateral distribution of impurity species as well as the size of impurity features. Small impurity striations are found at the triple phase boundary (TPB) as well as on the former electrode–electrolyte interface and the impurity features were found to be influenced by the electrode configuration and the initial behavior of the Ni electrode during thermal exposure (creep or shrinkage). Furthermore, the electrochemical performance (the line specific resistance LSR) was compared to data reported for Ni point anodes. Good agreement was obtained for data with comparable impurity features. Additionally, an order of magnitude estimation of the effect of SiO₂ content on surface coverage with an impurity film is performed for different electrode designs (point, patterned and cermet anode) and shows different preconditions for model anodes and nano- or microstructured cermet anodes. With typical impurity levels, a complete coverage of the electrolyte surface with SiO₂ seems almost inevitable in the case of model anodes.

La₀.₉₉Co₀.₄Ni₀.₆O₃₋δ–Ce₀.₈Gd₀.₂O₁.₉₅ as composite cathode for solid oxide fuel cells

We have studied a new composite SOFC cathode consisting of LaCo₀.₄Ni₀.₆O₃₋δ–5 (LCN60) and Ce₀.₉Gd₀.₁O₁.₉₅ (CGO). The polarisation resistance (RP) at 750°C and OCV was measured to 0.05±0.01Ωcm² and the activation energy was determined to be about 1eV. The impedance spectra were modelled with an EQC model consisting of a high frequency ZRQ circuit and a medium frequency Gerischer impedance, ZG. The resistance of ZG was found to decrease with approximately a factor of two as a consequence of infiltration of (La₀.₆Sr₀.₄)₀.₉₉CoO₃ into the porous LCN60–CGO structure. RP of both infiltrated and non-infiltrated LCN60–CGO cathodes is substantially lower than that of LSM–YSZ and comparable with single phase LSC cathodes at low T due to its low EA. RP was also found to be stable at 750°C and OCV. The cathodes were integrated onto ScYSZ based anode supported cells which were measured to have an ASR of 0.16–0.18Ωcm² at 750°C.
Limitations of potentiometric oxygen sensors operating at low oxygen levels

The electrochemical processes that limit the range of oxygen partial pressures in which potentiometric oxygen sensors can be used, were analysed using a theoretical and an experimental approach. Electrochemical impedance spectroscopy was performed on porous Pt/yttria stabilised zirconia (YSZ) electrodes between 10−6 and 0.2 bar and at temperatures between 500 and 950 °C. The flow of oxide ions and electron holes through a sensor cell, with a YSZ electrolyte, were calculated under similar conditions. The oxygen permeation of the sensor cell was insignificant at an oxygen partial pressure of 10−6 bar for an inlet flow rate higher than 2 L h−1 between 600 and 800 °C. The polarisation resistance measured between 10−6 and 10−4 bar was found to be inversely proportional to the oxygen partial pressure, nearly temperature independent and inversely proportional to the inlet gas flow rate, which shows that gas phase mass transport processes were dominating. The time constant of the gas phase mass transport processes was found to be inversely proportional to the oxygen partial pressure. The response time of these processes therefore limits the oxygen partial pressure range in which potentiometric oxygen sensors can be used.

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Low temperature reduction of NO and O2 on A-site deficient (Pr0.6Sr0.4)1−sFe0.8Co0.2O3−δ perovskites

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Materials and Manufacturing of Electrochemical Cells for Reduction of CO2 into Liquid Fuels

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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 ºC 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
Method and system for purification of gas streams for solid oxide cells

The present invention provides in embodiments a method for purification of inlet gas streams for a solid oxide cell operated in both, electrolysis and fuel cell mode, the solid oxide cell comprising at least a first electrode, an electrolyte and a second electrode, the method comprising the steps of: - providing at least one scrubber in the gas stream at the inlet side of the first electrode of the solid oxide cell; and/or providing at least one scrubber in the gas stream at the inlet side of the second electrode of the solid oxide cell; and - purifying the gas streams towards the first and second electrode; wherein the at least one scrubber in the gas stream at the inlet side of the first electrode and/or the at least one scrubber in the gas stream at the inlet side of the second electrode comprises a material suitable as an electrolyte material and a material suitable as an electrode material, and wherein the material suitable as an electrolyte material and a material suitable as an electrode material form triple phase boundaries similar to or identical to the triple phase boundaries of the electrode for which the gas stream is purified with the at least one scrubber.

Modifications of interface chemistry of LSM–YSZ composite by ceria nanoparticles

A porous composite electrode LSM–YSZ (lanthanum strontium manganite and yttria stabilized zirconia) was impregnated with different amounts of SDC (samarium substituted ceria) nanoparticles. The materials were investigated with X-ray diffraction, scanning electron microscopy, transmission electron microscopy and X-ray photoelectron spectroscopy to determine the microstructure, the interface chemistry and the surface chemistry of the various impregnated samples. The SDC nanoparticles cover the surface of the LSM–YSZ backbone to a large extent; they are approximately 5–20 nm in diameter and have a cubic crystal structure. Low concentrations of lanthanum and manganese originating from LSM were detected within SDC particles. It was also observed that the relative atomic concentration of strontium increased on the LSM–YSZ surface with increasing amount of SDC nanoparticles. These findings are related to the applied nanoparticle impregnation method. It is indicated that interactions between surfactant, nanoparticles, impregnation solution and the LSM–YSZ composite take place which can locally affect the surface and interface chemistry of the investigated materials.
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 gases 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.
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: RNi,TPB(t) = RNi,0 + ΔR•(1 − exp(− t / τ)). The initial resistance and total increase for the Ni–YSZ charge transfer resistance, RNi,0 and ΔR, were similar for all tests (i.e. not directly correlated with p(H₂O)), but the characteristic time, τ, 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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Optimizing the Performance of Porous Electrochemical Cells for Flue Gas Purification using the DOE method
The DOE model was used to improve the performance of cells for electrochemical gas purification. Three factors were chosen: the amount of graphite, the Lanthanum Strontium Manganate/Gadolinium-doped Cerium oxide weight % ratio, and the Lanthanum Strontium Manganate pre-calcination temperature (with or without Lanthanum Strontium Manganate calcinated at 1000 °C). The effects of the following physical properties were measured: porosity, pore size, shrinkage, and conductivity. The sintered tapes were also characterized with scanning electron microscopy. Graphite was added as a pore former. The work shows, that a change in a factor not only changes the performance property that one would expect, but also influence other properties.

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Contributors: Andersen, K. B., Nygaard, F. B., He, Z., Menon, M., Kammer Hansen, K.
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Publication information
Optimizing the performance of porous thin films of strontium doped lanthanum ferrite

Electrical conductivity relaxation measurements were carried out on thin films of (La0.6Sr0.4)0.99 FeO3−δ deposited on MgO (100) substrates by pulsed laser deposition in order to determine the surface exchange coefficient, k_{Ex}, of the oxygen incorporation process in the temperature range 550–700°C. The composition of the films was verified using wavelength dispersive x-ray and Rutherford backscattering spectroscopy. Scanning electron microscopy showed small triangular crystallites with the largest dimension 80 nm and the smallest dimension 10 nm. X-ray diffraction showed a cubic perovskite structure and significant texturing. At a constant temperature, k_{Ex} was found to be a function only of the final pO2 of the pO2-changes the sample was subjected to during conductivity relaxation experiments, confirming that the magnitude of the exchange coefficient was not influenced by changes in ionic defect concentrations. The k_{Ex}-values determined for these thin films were significantly lower than for bulk samples. A value of 3.6 × 10−6 cm s−1 was obtained at 702°C and a final pO2 of 0.048 atm, approximately a factor of six lower than that obtained for bulk samples. An activation energy of 282 ± 20 kJ mol−1 was found for the surface exchange coefficient at pO2 = 0.048 atm. Possible reasons for the reduced magnitude of k_{Ex} are discussed including the role of thermal history in influencing surface morphology and chemistry.
**Oxygen permeation in thin, dense Ce0.9Gd0.1O 1.95- membranes II. experimental determination**

Thin (~30 m), dense Ce0.9Gd0.1O1.95- (CGO10) membranes (5 cm2+) supported on a porous NiO/YSZ substrate were fabricated by tape casting, wet powder spraying and lamination. A La0.58Sr0.4Co0.2Fe0.8O3-δ/Ce0.9Gd0.1O1.95- (LSCF/CGO10) composite cathode was applied by screen printing. Oxygen permeation measurements and electrochemical characterisation of the cells were performed as a function of temperature with air and varying hydrogen/steam mixtures flowing in the feed and permeate compartments, respectively. The oxygen flux was found to reach 10 N mL min-1 cm-2 at ~1100 K and to exceed 16 N mL min-1 cm-2 at 1175 K. The measured oxygen flux was in good agreement with theoretical predictions from a model that takes into account the bulk transport properties of Ce0.9Gd0.1O1.95-, the anode and cathode polarisation resistances, and the gas conversion and gas diffusion losses in the permeate compartment. The performance of the membrane was also investigated under varying CH4 and H2O gas mixtures at 1106 K. The oxygen flux increased with decreasing steam to carbon ratio and was found to exceed 10 N mL min-1 cm-2 of O2 for steam to carbon ratios below 4:3. Post-test analysis of the tested membrane did not reveal any significant microstructural degradation of the CGO10 membrane or the anode-support. © 2011 The Electrochemical Society.

**General information**

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**Oxygen permeation in thin, dense Ce0.9Gd0.1O 1.95- membranes I. Model study**

A model of a supported planar Ce0.9Gd0.1O1.95- oxygen membrane in a plug-flow setup was constructed and a sensitivity analysis of its performance under varying operating conditions and membrane parameters was performed. The model takes into account the driving force losses at the catalysts at the feed and permeate side of the membrane, related to the gaseous oxygen reduction and fuel oxidation, respectively, as well as the gas conversion and gas diffusion resistances in the porous support structure at the permeate side. The temperature and oxygen activity dependence of the oxide ionic and electronic conductivity and the oxygen nonstoichiometry of Ce0.9Gd0.1O1.95- were described based on literature data. The performance of the membrane was characterised by the delivered oxygen flux and the membrane voltage. The dependence of the performance on the various membrane and operating parameters was analyzed by a separation of the various losses. The chemical expansion of Ce 0.9Gd0.101.95-5 under operation was estimated from the calculated oxygen activity and nonstoichiometry profiles inside the membrane. © 2011 The Electrochemical Society.

**General information**

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Performance and durability of solid oxide electrolysis cells for syngas production

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Organisations: Electrochemical Evaluation, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrocermics, Microstructures and Interfaces, Electrochemistry
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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. For example, increased resistance against mechanical and thermal stresses and a reduction in material costs. When Ni-YSZ based anodes are used in metal supported SOFC, elements from the active anode layer may inter-diffuse with the metallic support during sintering. This work illustrates how the inter-diffusion 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 electrochemical performance and durability of the novel planar metal-supported SOFC design. The electrode performance on symmetrical cells has also been evaluated. The novel cell and anode design shows a promising performance and durability at a broad range of temperatures and is especially suitable for intermediate temperature operation at around 650°C. © 2011 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

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Contributors: Blennow Tullmar, P.; Hjelm, J.; Klemensø, T., Persson, Å. H., Ramousse, S., Mogensen, M. B.
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Recent advances in ceramic based reversible fuel cells/electrolyser cells

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Contributors: Mogensen, M. B.
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Routes to Synthetic Fuels

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Contributors: Mogensen, M. B.
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Routes towards affordable storage of sustainable energy

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SOFC LSM:YSZ cathode degradation induced by moisture: An impedance spectroscopy study
The cause of the degradation effect of moisture during operation of LSM cathode based SOFCs has been investigated by means of a detailed impedance characterization on LSM:YSZ composite cathode based SOFCs. Further the role of YSZ as cathode composite material was studied by measurements on SOFCs with a LSM:CGO composite cathode on a CGO interdiffusion barrier layer. It was found that both types of cathodes showed similar electrochemical characteristics towards the presence of moisture during operation. Upon addition and removal of moisture in the fed air the impedance study showed a change in the high frequency cathode arc, which is associated with the charge transport/transfer at the LSM/YSZ interface. On prolonged operation with the presence of moisture an ongoing increase in the high frequency cathode arc resulted in a permanent loss of cathode/electrolyte contact and thus increase in the serial resistance and the high and low frequency cathode arcs. On the basis of these results and reports within literature a mechanism for the effect of moisture was proposed, which attribute to moisture the role of participating in an enhanced removal of manganese from the LSM/YSZ interface and thus eventually a decomposition of LSM.

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Solid oxide cells for steam electrolysis
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Strontium zirconate as silicon and aluminum scavenger in yttria stabilized zirconia
Here we report on strontium zirconate as a getter for silicon dioxide and aluminum oxide in yttria stabilized zirconia (YSZ) single crystals for cleaning purposes. YSZ single crystals were covered with strontium zirconate powder and heat treated...
at 1450°C in water vapor. After treatment the YSZ single crystals showed homogeneously distributed ball-sectioned features (bumps) across the external surface of the crystal. The composition as quantified by energy-dispersive X-ray spectroscopy (EDS) showed a large enrichment of silicon and aluminum in the bumps. From cross-section analysis by transmission electron microscopy (TEM) the interface region between bump and YSZ single crystal bulk was examined. EDS showed a homogeneous distribution of silicon and aluminum through the cross section of a bump. The results suggest strontium zirconate as a good getter for silicon and aluminum from bulk materials at elevated temperatures and prove a route to remove trace bulk impurities in YSZ.

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**Sustainable hydrocarbon fuels by recycling CO2 and H2O with renewable or nuclear energy**
To improve the sustainability of transportation, a major goal is the replacement of conventional petroleum-based fuels with more sustainable fuels that can be used in the existing infrastructure (fuel distribution and vehicles). While fossil-derived synthetic fuels (e.g. coal derived liquid fuels) and biofuels have received the most attention, similar hydrocarbons can be produced without using fossil fuels or biomass. Using renewable and/or nuclear energy, carbon dioxide and water can be recycled into liquid hydrocarbon fuels in non-biological processes which remove oxygen from CO2 and H2O (the reverse of fuel combustion). Capture of CO2 from the atmosphere would enable a closed-loop carbon-neutral fuel cycle. This article critically reviews the many technological pathways for recycling CO2 into fuels using renewable or nuclear energy, considering three stages—CO2 capture, H2O and CO2 dissociation, and fuel synthesis. Dissociation methods include thermolysis, thermochemical cycles, electrolysis, and photoelectrolysis of CO2 and/or H2O. High temperature co-electrolysis of H2O and CO2 makes very efficient use of electricity and heat (near-100% electricity-to-syngas efficiency), provides high reaction rates, and directly produces syngas (CO/H2 mixture) for use in conventional catalytic fuel synthesis reactors. Capturing CO2 from the atmosphere using a solid sorbent, electrolysing H2O and CO2 in solid oxide electrolysis cells to yield syngas, and converting the syngas to gasoline or diesel by Fischer–Tropsch synthesis is identified as one of the most promising, feasible routes. An analysis of the energy balance and economics of this CO2 recycling process is presented. We estimate that the full system can feasibly operate at 70% electricity-to-liquid fuel efficiency (higher heating value basis) and the price of electricity needed to produce synthetic gasoline at U.S.D$ 2/gal ($ 0.53/L) is 2–3 U.S. cents/kWh. For $ 3/gal ($ 0.78/L) gasoline, electricity at 4–5 cents/kWh is needed. In some regions that have inexpensive renewable electricity, such as Iceland, fuel production may already be economical. The dominant costs of the process are the electricity cost and the capital cost of the electrolyzer, and this capital cost is significantly increased when operating intermittently (on renewable power sources such as solar and wind). The potential of this CO2 recycling process is assessed, in terms of what technological progress is needed to achieve large-scale, economically competitive production of sustainable fuels by this method.

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Sustainable hydrocarbon fuels from co-electrolysis of CO₂ and steam

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Synthetic fuel production using pressurized solid oxide electrolysis cells

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The Effect of Humidity and Oxygen Partial Pressure on LSM–YSZ Cathode
Two series of anode supported solid oxide fuel cells (SOFC) were prepared, one with a composite cathode layer of lanthanum strontium manganite (LSM) and yttria stabilized zirconia (YSZ) on top and the other further has a LSM current collector layer on top. The fuel cells were heat treated at 1,000 °C in air or nitrogen choosing dry or humid (70% steam) conditions. XRD, SEM, and XPS investigations were performed on the various samples. The most severe modifications were observed in humid nitrogen atmosphere at low oxygen partial pressure. LSM surface change goes along with a decrease of manganese concentration and strontium enrichment on the surface of the materials. Formation of monoclinic zirconia and zirconate phases was also observed. These results give a closer insight into possible degradation mechanisms of SOFC composite cathode materials in dependence of humidity and oxygen partial pressure.
The Strategic Electrochemical Research Center in Denmark
A 6-year strategic electrochemistry research center (SERC) in fundamental and applied aspects of electrochemical cells with a main emphasis on solid oxide cells was started in Denmark on January 1st, 2007 in cooperation with other Danish and Swedish Universities. Furthermore, 8 Danish companies are taking part in the center. Now after 4 years both new equipment and methods have been developed and new scientific and technical results have been generated in relation to four technical applications, namely fuel cells, electrolyzers, gas cleaners and oxygen sensors. Selected techniques and results are presented. ©2011 COPYRIGHT ECS - The Electrochemical Society

Towards Quantification of Relations Between Electrode Polarisation and Microstructure
The total cell resistances of three Riso DTU solid oxide fuel cells (SOFCs) were broken down into individual contributions, by the combined use of electrochemical impedance spectroscopy (EIS), and complex non-linear least squares fitting
Information on the number of contributing processes, frequency regions, and thermal behaviour, was obtained from symmetric cell studies of individual electrodes. The frequency regions dominated by electrode specific processes in the full cells were assessed by systematic changes of temperature and/or partial pressure of reactant gases on both electrodes. Based on the combined information, an equivalent circuit consisting of a series resistance (R-s) and five (RQ) elements was found suitable to describe the polarisation resistance of all tested cells. The breakdown process also allowed the assessment of limitations, and possible simplifications. The proposed electrochemical analysis correlated well with the exhibited microstructural features of the cells, which were produced with different compositions and/or production parameters. (C) 2011 The Electrochemical Society. [DOI: 10.1149/1.3587113] All rights reserved.
A Composite Glass Seal for a Solid Oxide Electrolyser Cell Stack

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Atmosphere, temperature and pressure dependent segregation of bulk impurities in yttria-stabilized zirconia

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Cathode-Electrolyte Interfaces with CGO Barrier Layers in SOFC
Electron microscopy characterization across the cathode–electrolyte interface of two different types of intermediate temperature solid oxide fuel cells (IT-SOFC) is performed to understand the origin of the cell performance disparity. One IT-SOFC cell had a sprayed-cosintered Ce0.90Gd0.01O1.95 (CGO10) barrier layer, the other had a barrier layer deposited by pulsed laser deposition (PLD) CGO10. Scanning electron microscopy, transmission electron microscopy (TEM), and electron backscattered diffraction (EBSD) investigations conclude that the major source of the cell performance difference is attributed to CGO–YSZ interdiffusion in the sprayed-cosintered barrier layer. From TEM and EBSD work, a dense CGO10 PLD layer is found to be deposited epitaxially on the YSZ electrolyte substrate—permitting a small amount of SrZrO3 formation and minimizing CGO–YSZ interdiffusion.

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Ceramics in Solid Oxide Electrolyzer and Fuel Cells

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Ceria and strontium titanate based electrodes
A ceramic anode structure obtainable by a process comprising the steps of: (a) providing a slurry by dispersing a powder of an electronically conductive phase and by adding a binder to the dispersion, in which said powder is selected from the group consisting of niobium-doped strontium titanate, vanadium-doped strontium titanate, tantalum-doped strontium titanate, and mixtures thereof, (b) sintering the slurry of step (a), (c) providing a precursor solution of ceria, said solution containing a solvent and a surfactant, (d) impregnating the resulting sintered structure of step (b) with the precursor solution of step (c),(e) subjecting the resulting structure of step (d) to calcination, and (f) conducting steps (d)-(e) at least once.
Characterization of (La$_{1-x}$Sr$_x$)$_2$MnO$_3$ and Doped Ceria Composite Electrodes in NO$_x$-Containing Atmosphere with Impedance Spectroscopy

This study used electrochemical impedance spectroscopy (EIS) to characterize composite metal oxide electrodes in atmospheres containing NO, NO$_2$, and O$_2$. Symmetrical cells with electrodes of (La$_{1-x}$Sr$_x$)$_2$MnO$_3$ [(x, s) = (0.15, 0.9) and (0.5, 0.99)] and doped ceria (Ce$_{0.9}$Gd$_{0.1}$O$_2$ and Ce$_{1-x}$Gd$_x$O$_2$ (x=0.1, 0.2)] were subjected to EIS while varying the temperature (from 300 to 600°C), the composition of the atmosphere, and the gas flow. The impedance spectra were fitted to equivalent circuits, and common arcs were identified and sought related to physical and chemical processes. The electrodes had a much lower polarization resistance (Rp) when NO or NO$_2$ was present in the atmosphere at low temperatures (300–400°C) than in air. The impedance spectra for electrodes in 1% NO in Ar were dominated by a low frequency arc at high temperatures (500–600°C). This arc seemed to be a type of conversion arc, which is related to a gaseous intermediate (possibly NO$_2$), formed from NO, through which the electrode reaction occurs. Indications were found that the electrodes are not electrochemically active toward NO around open-circuit voltages. ©2010 The Electrochemical Society
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.

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Composite Material Suitable for Use as Electrode Material in a SOC

The present invention relates to composite material suitable for use as an electrode material in a solid oxide cell, said composite material consist of at least two non-miscible mixed ionic and electronic conductors. Further provided is a composite material suitable for use as an electrode material in a solid oxide cell, said composite material being based on \((\text{Gd}_{1-x}\text{Sr}x)_{1-s}\text{Fe}_{1-y}\text{Co}y\text{O}_3-[\delta]\) or \((\text{Ln}_{1-x}\text{Sr}x)_{1-s}\text{Fe}_{1-y}\text{Co}y\text{O}_3-[\delta])\) wherein \(\text{Ln}\) is a lanthanide element, Sc or Y, said composite material comprising at least two phases which are non-miscible, said composite material being obtainable by the glycine nitrate combustion method. Said composite material may be used for proving an electrode material in the form of at least a two-phase system showing a very low area specific resistance of around 0.1 \([\Omega]\text{cm}^2\) at around 600 DEG C.

Continuum mechanics simulations of NiO/Ni-YSZ composites during reduction and re-oxidation

Repeated reduction–oxidation (redox) cycles on Ni-based solid oxide fuel cells (SOFC) have been experimentally well investigated and are known to be detrimental to the thermomechanical stability of the composites, especially on anode supported structures. In the present work the mechanistic analysis of the internal factors leading to the dimensional changes and the thermomechanical instability have been addressed, to our knowledge for the first time, using continuum mechanics simulations. The two intertwined percolating phases, YSZ and NiO/Ni, interact and the driving force for the dimensional change arises from the volumetric change related to the phase change NiO ↔ Ni. The measurable change in bulk length is given by the ceramic YSZ backbone as a response to the stress created by the chemical strain. The different subprocesses described in the model for YSZ were elastic and anelastic expansion, diffusional creep, grain boundary sliding (GBS) and microcracking due to excessive stress. In the Ni/NiO phase, nonelastic strains in terms of diffusional and power law creep were implemented, and additionally for NiO deformation due to microcracking and/or pseudoplasticity. Semi-empirical correlations were employed for creep limiting grain growth of Ni and NiO, particle coarsening of Ni and particle growth in NiO during the oxidation. Seven experimental cases of high temperature redox
dilatometry were simulated. The model shows good qualitative agreement with the measurements. The different processes of importance for the dimensional behaviour are discussed.

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Contributors: Pihlatie, M., Frandsen, H. L., Kaiser, A., Mogensen, M. B.
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Corrosion stability of ferritic stainless steels for solid oxide electrolyser cell interconnects
Long-term oxidation behaviour of eight ferritic steels with 20–29 wt.% chromium (F 20 T, TUS 220 M, AL 453, Crofer 22 APU, Crofer 22 H, Sanergy HT, E-Brite and AL 29-4C) has been studied. The samples were cut into square coupons, ground and annealed for 140–1000 h at 1173 K in flowing, wet hydrogen, air and pure oxygen. The reaction kinetics was followed by mass increase of individual samples over time. Parabolic rate law was observed for most measurements. The respective rate constants have been evaluated and compared. The chemical composition of the oxide scale was investigated by XRD and SEM/EDXS. The major constituent is chromium oxide. Other oxides, such as (Mn, Cr)3O4, MnTiO3, SiO2 or Al2O3, are also present in different amounts depending on the chemical composition of the steel. The oxidation rate increases with increasing oxygen partial pressure and decreasing chromium concentration. Chromium diffusion coefficients in Cr2O3 and parabolic rate constants are compared. The reaction mechanism for the chromia formation is suggested. The results are discussed with respect to the applications of the steels in a working solid oxide electrolyser cell stack. Furthermore, suggestions for the development of a superior alloy composition are given.

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Keywords: Fuel Cells and hydrogen, Electrolysis
DOIs:
Defect structure, electronic conductivity and expansion of properties of \((\text{La}_{1-x}\text{Sr}_x)\text{Co}_{1-y}\text{Ni}_y\text{O}_{3-\delta}\)

This study reports on oxygen nonstoichiometry, electronic conductivity and lattice expansion of three compositions as function of \(T\) and \(\text{PO}_2\) in the \((\text{La}_{1-x}\text{Sr}_x)\text{Co}_{1-y}\text{Ni}_y\text{O}_{3-\delta}\) \((x=0.1, y=0.4; x=0.1, y=0.3; x=0.2, y=0.2)\) materials system. The nonstoichiometry data were successfully fitted using the itinerant electron model which indicates the existence of delocalized electronic states. This was also reflected in the high electronic conductivities, above 1000 \( \text{S cm}^{-1} \), measured for all three compositions. The electronic conductivity was shown to decrease linearly with the oxygen nonstoichiometry parameter, \(\delta\), supporting that the conductivity is dependent on p-type charge carriers. Comparing calculated p-type mobilities with data reported in literature on \(\text{La}_{1-x}\text{Sr}_x\text{CoO}_3\) indicated that Ni-substitution into \((\text{La}_{1-x}\text{Sr}_x)\text{CoO}_3-\delta\) increases the p-type mobility. The electronic conductivity was also found to be dependent on intrinsic charge related to spin excitations and Ni substitution rather than the p-type charge. A conductivity mechanism is hypothesized including a metallic like conductivity of the p-type charge and a small polaron conductivity of the intrinsic charge. Lattice expansion as function of \(T\) and \(\delta\) was successfully described using first and second order thermal and chemical expansion coefficients. Substituting 10% Co with Ni in \((\text{La}_{0.6}\text{Sr}_{0.4})_{0.99}\text{CoO}_3-\delta\) was found to decrease the apparent thermal expansion with about 25%.

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Durability of SOFCs using sulphur containing fuels

General information
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Contributors: Hagen, A., Rasmussen, J. F. B.
Publication date: 2010

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Effect of impregnation of La$_{0.85}$Sr$_{0.15}$MnO$_3$/Yttria Stabilized Zirconia Solid Oxide Fuel Cell cathodes with La$_{0.85}$Sr$_{0.15}$MnO$_3$ or Al$_2$O$_3$ nano-particles

Strontium substituted lanthanum manganite and yttria stabilized zirconia solid oxide fuel cell composite electrodes were impregnated with nano-particles of strontium substituted lanthanum manganite or alumina. A clear positive effect was observed on low performing electrodes and on good performing electrodes if the temperature was kept low after the impregnation with strontium substituted lanthanum manganite. On good performing electrodes the effect disappeared on heating. Alumina nano-particles had a detrimental effect on the activity of the strontium substituted lanthanum manganite based electrodes.

EIS measurements on La$_{1-x}$Sr$_x$Co$_{1-y}$Fe$_y$O$_{3-\delta}$ based composite electrodes in NO$_x$ containing atmosphere

EIS measurements on La$_{1-x}$Sr$_x$Co$_{1-y}$Fe$_y$O$_{3-\delta}$ based composite electrodes in NO$_x$ containing atmosphere
Electrochemical characterization and performance evaluation

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Research output: Contribution to conference – Paper – Annual report year: 2010 – Research

Electrochemical Characterization of Ni/(Sc)YSZ Electrodes
Investigations of Ni/(Sc)YSZ cerments for solid oxide cells (SOCs) were performed by electrochemical impedance spectroscopy (EIS), under varying experimental conditions and upon redox cycling, using three different designs of symmetric cells. The deconvolution and fitting of the obtained impedance spectra was performed using a combination of distribution of relaxation times (DRT) and complex nonlinear least squares fitting routine (CNLS). The exhibited behaviours allowed the attribution of each contribution to a specific process, and correlated with production methods and microstructural parameters. Initial degradation results for both Ni/ScYSZ and Ni/YSZ based anodes under very high steam content are also reported. ©2010 COPYRIGHT ECS - The Electrochemical Society

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Electrochemical investigation of nickel pattern electrodes in H₂/H₂O and CO/CO₂ atmospheres
In this study, nickel pattern electrodes were electrochemically investigated in a three-electrode setup, operating both with H₂ / H₂O and CO/CO₂ atmospheres. Heating introduced structural differences in the nickel layer among the pattern electrodes, which appear to affect the electrode performance. Both dense and porous nickel pattern electrodes were formed by heating. Holes appeared in the nickel layer of the porous pattern electrodes, where the open cavity triple phase
boundaries exhibited different limiting processes than open triple phase boundary electrodes of the dense electrode. As the temperature was raised in the experiment, the electrodes stabilized, with a degraded behavior that seemed to be strongly coupled to the structural changes in the electrode. It was possible to compare literature results with high temperature impedance measurements in H2 / H2 O presented here, while new results at lower temperatures in H2 / H2 O are also presented. Impedance spectroscopy measurements were performed, and the gas dependence of the polarization resistance was observed as the mixture ratios and temperatures were varied in both atmospheres. A positive relation between the polarization resistance and the partial pressure of CO was determined for the dense nickel pattern electrode, which agrees with previous results using nickel point electrodes. © 2010 The Electrochemical Society.
Electrochemical Reduction of NOx Gases on Spinel-Type Electrode Materials

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Contributors: Bræstrup, F. R., Kammer Hansen, K.
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Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2010 › Research › peer-review

Electrochemical Reduction of Oxygen and Nitric Oxide at Low Temperature on La1-xSrxCoO3-delta Cathodes
Six La1-xSrxCoO3- (x= 0, 0.05, 0.15, 0.25, 0.35, 0.50) perovskites were synthesised and characterised by powder XRD and cyclic voltammetry on cone-shaped electrodes in either air or nitric oxide in argon at 200, 300 and 400°C. At 200°C the current densities in air was highest for the strontium free cobaltite, whereas the current densities was highest for La0.95Sr0.05CoO3- in the nitric oxide containing atmosphere. This was also the compound with the highest INO/O2 current ratio at 200°C. At higher temperatures a limiting cathodic current was observed for all of the cobaltite’s, except La0.50Sr0.50CoO3-, in both air and the nitric oxide containing atmosphere. This was attributed to a rate limiting chemical step (i.e. dissociation of oxygen or nitric oxide) in the reaction sequence.

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Web of Science (2010): Impact factor 2.427
Web of Science (2010): Indexed yes
Original language: English
Electrochemical removal of NOx with porous cell stacks

In this study porous cell stacks were investigated for their ability to remove NOx electrochemically. The cell stacks were made from laminated tapes of porous electrolyte Ce0.9Gd0.1O1.95 and composite electrodes of La1−xSrxFxMnO3 (x = 0.15, and 0.5) and ceria doped with Gd or Pr. The cell stacks were infiltrated with nano-particles of pure ceria, Ce0.9Gd0.1O1.95 and Ce0.8Pr0.2O2−δ after sintering. A gas stream containing NO were sent through the cell stack. When the cell stacks were polarised with 0.75 V per cell then it was possible to remove some of the NOx in the temperature interval of 250–400 °C. The cell stacks infiltrated with ceria showed the highest activity, while the ones infiltrated with Ce0.9Gd0.1O1.95 had the highest selectivity towards NO compared to O2. When the cell stack was polarised with 1.5 V for each cell it was possible to remove up to 35% of NO present.
Electrochemical Removal of NOx-Gasses by Use of LSM-Cathodes Impregnated with a NOx Storage Compound

Electrochemical decomposition of NO on La0.85Sr0.15MnO3--Ce0.90Gd0.10O1.95 electrodes with and without KNO3 impregnation is investigated. The KNO3 is added as this compound is expected to work as a NOx-storage compound. Measurements are made in the temperature range 300-400 degree C and in three different atmospheres: 1000 ppm NO, 10% O2 and 1000 ppm NO + 10% O2. Electrochemical impedance spectroscopy and cyclic voltammetry are used for electrochemical characterization of the electrodes, and the conversion of NO and O2 is measured on a mass-spectrometer. The results show a significant increase in the NO-conversion, when KNO3 is added to the La0.85Sr0.15MnO3--Ce0.90Gd0.10O1.95 electrodes. ©2010 COPYRIGHT ECS - The Electrochemical Society

Exceptional Durability of Solid Oxide Cells

Extensive efforts to resolve the degradation normally associated with solid oxide electrolysis cells (SOECs) have been conducted during the past decade. To date, the degradation is assumed to be caused by adsorption of impurities in the cathode, although no firm evidence for this degradation mechanism has been presented. In this article, we demonstrate that the rapid degradation of these SOECs is indeed caused by impurities, and that operation without degradation is possible when removing these impurities from the inlet gases. Cleaning the inlet gases may be a solution for operating SOECs without long-term degradation.
Experimental determination of the Onsager coefficients of transport for Ce$_{0.8}$Pr$_{0.2}$O$_{2-\delta}$

For a mixed oxide-ion and electron conducting oxide, with oxygen vacancies and electrons ($e^-$) or holes ($h^+$) as charge carriers, a flux of ($J_i$) can in principle be driven, not only directly by its own electrochemical potential gradient ($\nabla \eta_i$), but also indirectly by that of electrons ($\nabla \eta_e$), and vice versa for the flux of electrons ($J_e$). It is common practice to assume that electrons and mobile ions migrate independently, despite the lack of experimental evidence in support of this. Here, all the Onsager coefficients, including the cross coefficients, have been measured for Ce$_{0.8}$Pr$_{0.2}$O$_{2-\delta}$ within the aO$_2$ range $10^{-21}$–$10^{-1}$ at 800 °C, using local ionic and electronic probes in a four-probe configuration. The cross coefficients of transport were found to be negligible in comparison to the direct coefficients in the aO$_2$ range $10^{-21}$–$10^{-4}$, but of the same order of magnitude as the direct coefficients for high aO$_2$ values ($10^{-2}$–$1$). This is in contrast to the commonly used assumption that the two types of carriers migrate independently, i.e. that $L_{ie} = 0$.

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High Performance Fe-Co Based SOFC Cathodes

With the aim of reducing the temperature of the solid oxide fuel cell (SOFC), a new high-performance perovskite cathode has been developed. An area-specific resistance (ASR) as low as 0.12 \( \Omega \text{cm}^2 \) at 600 °C was measured by electrochemical impedance spectroscopy (EIS) on symmetrical cells. The cathode is a composite between \((\text{Gd}_0.6\text{Sr}_0.4)0.99\text{Fe}_0.8\text{Co}_0.2\text{O}_3-\delta\) (GSFC) and \(\text{Ce}_0.9\text{Gd}_0.1\text{O}_1.95\) (CGO10). Examination of the microstructure of the cathodes by scanning electron microscopy (SEM) revealed a possibility of further optimisation of the microstructure in order to increase the performance of the cathodes. It also seems that an adjustment of the sintering temperature will make a lowering of the ASR value possible. The cathodes were compatible with ceria-based electrolytes but reacted to some extent with zirconia-based electrolytes depending on the sintering temperature.

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Hydrogen and synthetic fuel production using pressurized solid oxide electrolysis cells

Wind and solar power is troubled by large fluctuations in delivery due to changing weather. The surplus electricity can be used in a Solid Oxide Electrolyzer Cell (SOEC) to split \( \text{CO}_2 + \text{H}_2\text{O} \) into \( \text{CO} + \text{H}_2 \) (+O2). The synthesis gas (CO + H2) can subsequently be catalyzed into various types of synthetic fuels using a suitable catalyst. As the catalyst operates at elevated pressure the fuel production system can be simplified by operating the SOEC at elevated pressure. Here we present the results of a cell test with pressures ranging from 0.4 bar to 10 bar. The cell was tested both as an SOEC and as a Solid Oxide Fuel Cell (SOFC). In agreement with previous reports, the SOFC performance increases with pressure. The SOEC performance, at 750 °C, was found to be weakly affected by the pressure range in this study, however the internal resistance decreased significantly with increasing pressure.

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Impact of Initial Reduction and H₂/H₂O Contents on the Performance and Microstructure of Ni Cermets

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Introduction to fuel cells: Fundamentals of electrochemical kinetics, thermodynamics and solid state chemistry for the experienced (I)

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Introduction to fuel cells - I.pdf
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Materials and structural aspects of solid oxide electrochemical cells for conversion of electricity to hydrocarbons and reverse

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Molybdate Based Ceramic Negative-Electrode Materials for Solid Oxide Cells
Novel molybdate materials with varying Mo valence were synthesized as possible negative-electrode materials for solid oxide cells. The phase, stability, microstructure and electrical conductivity were characterized. The electrochemical activity for H2O and CO2 reduction and H2 and CO oxidation was studied using simplified geometry point-contact electrodes. Unique phenomena were observed for some of the materials - they decomposed into multiple phases and formed a nanostructured surface upon exposure to operating conditions (in certain reducing atmospheres). The new phases and surface features enhanced the electrocatalytic activity and electronic conductivity. The polarization resistances of the best molybdates were two orders of magnitude lower than that of donor-doped strontium titanates. Many of the molybdate materials were significantly activated by cathodic polarization, and they exhibited higher performance for cathodic (electrolysis) polarization than for anodic (fuel cell) polarization, which makes them especially interesting for use in electrolysis electrodes. ©2010 COPYRIGHT ECS - The Electrochemical Society

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Ni based solid oxide cell electrodes

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NiCr (x) Fe2-x O-4 as cathode materials for electrochemical reduction of NO (x)

Solid solutions of spinel-type oxides with the composition NiCr x Fe2-x O4 (x = 0.0, 0.5, 1.0, 1.5, 2.0) were prepared with the glycine–nitrate combustion synthesis. Four-point DC resistivity measurements show an increase in the conductivity as more Cr is introduced into the structure, whereas dilatometer measurements show that the linear thermal expansion decreases with increasing Cr content. The oxides were used as electrode materials in a pseudo-three-electrode setup in the temperature range of 300–600 °C. Cyclic voltammetry and electrochemical impedance spectroscopy were used to
characterize the electrochemical behavior in 1% NO, 1% NO2, and 10% O2. NiCr2O4 shows high activity in NO and NO2 relative to O2 and can therefore be considered as a possible electrode material. Peaks were detected in the voltammograms recorded on NiCr2O4 in 1% NO. The origin of the peaks seems to be related to the oxidation of Cr or the formation of nitrogen-containing species formed on the surface of the electrode.

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Braestrup, F. R., Kammer Hansen, K.
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Scopus rating (2010): SJR 0.897 SNIP 0.977
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Original language: English
Keywords: Fuel Cells and hydrogen, Flue gas purification
DOI: 10.1007/s10008-009-0801-x
Source: orbit
Source ID: 252191
Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review

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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Contributors: Hauch, A., Mogensen, M. B.
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Web of Science (2010): Impact factor 2.496
Opportunities and limitations of perovskite - fluorite composite ceramic electrodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
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Publisher: The Electrochemical Society
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Origin of Polarisation Losses in Solid Oxide Electrolysis Cells Operated at High Current Density

General information
Publication status: Published
Contributors: Knibbe, R., Ebbesen, S., Mogensen, M. B.
Pages: Abstract 1338
Publication date: 2010

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Title of host publication: Meeting Abstracts - Electrochemical Society
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Source: orbit
Source ID: 264336
Research output: Chapter in Book/Report/Conference proceeding → Conference abstract in proceedings – Annual report year: 2010 → Research → peer-review

Oxygen Nonstoichiometry and Defect Chemistry Modeling of Ce0.8Pr0.2O2-delta

The oxygen nonstoichiometry (delta) of Ce0.8Pr0.2O2−delta has been measured as a function of PO2 at temperatures between 600 and 900°C by coulometric titration and thermogravimetry. An ideal solution defect model, a regular solution
model, and a defect association model, taking into account the association of reduced dopant species and oxygen vacancies, were unable to reproduce the experimental results. However, excellent agreement with the experimentally determined oxygen nonstoichiometry could be achieved when using either a nonideal solution model with an excess enthalpic term linear in delta (\(\Delta H_{Pr}^{exc}=aH_{delta}\)) and a completely random distribution of defects (referred to as “delta-linear”), or a “generalized delta-linear” solution model, where the excess Gibbs energy change in the reduction reaction of the dopant linearly varies with delta (\(\Delta G_{Pr}^{exc}=aG_{delta}\)). A comparison of the partial molar enthalpy and entropy of oxidation, estimated from the defect models with those determined directly from the oxygen nonstoichiometry, suggests that the delta-linear solution model is the most appropriate in accounting for the observed nonideal reduction behavior of Pr.
Perspective and challenges of Solid Oxide Electrolysis

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Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
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Phase Formation in the System ZrO2–LaO1.5–MnOx in Air and PO2=1 Pa After 500 h of Annealing at 12001 and 14001 deg.C

The phase relation in the ZrO2–LaO1.5–MnOx system has been experimentally determined at 1200°C and 1400°C in air and at 1200°C in N2 (~100 Pa). Tie lines between LaMnO3 and t-ZrO2 and between LaMnO3 and La2Zr2O7 are observed at 1200°C in air. The geometry of the phase diagram changes at 1400°C in air due to the appearance of a stabilized ZrO2 phase, found to be of cubic symmetry by backscattered electron diffraction. Tie lines of LaMnO3–c-ZrO2, LaMnO3–La2Zr2O7, and c-ZrO2–La2Zr2O7 are observed. At 1200°C in N2 (~100 Pa), the LaMnO3–t-ZrO2 tie line observed at 1200°C in air is replaced by the La2Zr2O7–MnO tie line. Stabilization of c-ZrO2 is observed and a new compound forms, which is being reported for the first time. The proposed composition of the new compound is La2Zr5MnO14+δ.

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Microstructures and Interfaces
Contributors: Chatzichristodoulou, C., Chen, M., Bowen, J. R., Liu, Y.
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Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review

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.
Production of Synthetic Fuel by Electrolysis: Potential and Challenges

Prospects for large scale electricity storage in Denmark

Prospects for large scale electricity storage in Denmark
In a future power systems with additional wind power capacity there will be an increased need for large scale power management as well as reliable balancing and reserve capabilities. Different technologies for large scale electricity storage provide solutions to the different challenges arising with high wind power penetration. This paper presents a review of the electricity storage technologies relevant for large power systems. The paper also presents an estimation of the economic feasibility of electricity storage using the west Danish power market area as a case.

General information
Publication status: Published
Organisations: Composites and Materials Mechanics, Materials Research Division, Risø National Laboratory for Sustainable Energy, Electrochemistry, Fuel Cells and Solid State Chemistry Division
Contributors: Krog Ekman, C., Jensen, S. H.
Pages: 1140-1147
Removal of impurity phases from electrochemical devices
The present invention provides a solid oxide cell comprising a support layer, a first electrode layer, an electrolyte layer, and a second cathode layer, wherein at least one of the electrode layers comprises electrolyte material, a catalyst and agglomerated particles selected from the group consisting of alkali oxides, earth alkali oxides and transition metal oxides.
Sintering effect on material properties of electrochemical reactors used for removal of nitrogen oxides and soot particles emitted from diesel engines

In the present work, 12-layered electrochemical reactors (comprising five cells) with a novel configuration including supporting layer lanthanum strontium manganate (LSM)-yttria stabilised zirconia (YSZ), electrode layer LSM-gadolinia-doped cerium oxide (CGO) and electrolyte layer CGO were fabricated via the processes of slurry preparation, tape casting and lamination and sintering. The parameters of porosity, pore size, pore size distribution, shrinkage, flow rate of the sintered reactors and the electrical conductivities of the supporting layer and the electrode in the sintered reactors were characterised. The effect of sintering temperature on microstructures and properties of the sintered samples was discussed, and 1,250 °C was determined as the appropriate sintering temperature for reactor production based on the performance requirements for applications. Using the present ceramic processing route, porous, flat and crack-free electrochemical reactors were successfully achieved. The produced electrochemical reactors have the potential application in the removal of NOx and soot particles emitted from the diesel engines.

Solid oxide cells for conversion of electricity to hydrocarbons and reverse

Solid oxide fuel cells for conversion of electricity to hydrocarbons and reverse
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

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Contributors: Knibbe, R., Traulsen, M. L., Hauch, A., Ebbesen, S., Mogensen, M. B.
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Keywords: Fuel Cells and hydrogen, Electrolysis
DOI:
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Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review

Solid Oxide Fuel Cell: A method for producing a reversible solid oxid fuel cell

The solid oxide fuel cell comprising a metallic support material, an active anode layer consisting of a good hydrocarbon cracking catalyst, an electrolyte layer, an active cathode layer, and a transition layer consisting of preferably a mixture of LSM and a ferrite to the cathode current collector with means being provided for preventing diffusion between the metallic support and the active anode.

General information
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Contributors: Kammer Hansen, K., Wang, W., Halvor Larsen, P., Linderoth, S., Mogensen, M. B.
Publication date: 2010

Publication information
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Filing date: 08/12/2010
Original language: English
Keywords: Solid Oxide Fuel Cells, Fuel Cells and Hydrogen
Bibliographical note
Patent:
No.: WO2005122300

Patent:
No.: US2007269701
Solid State Electrochemical DeNOx: An overview

The literature on direct electrochemical reduction of NOx in a solid state cell has been reviewed. It is shown that the reduction of nitric oxide either occurs on the electrode or on the electrolyte if F-centers are formed. It is also shown that some oxide based electrodes have a high apparent selectivity towards the reduction of nitric oxide in a net oxidizing atmosphere. The activity and apparent selectivity of oxide based electrodes is strongly dependent on the composition of the oxide. The selectivity of noble metal based electrodes is generally very low. However, coating of noble metal based electrodes can give current efficiencies of up to 20% even in the presence of large amounts of oxygen.

Studies on solid oxide electrolysis cells -aspect of synthetic hydrocarbon fuel production

General information

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Riso National Laboratory for Sustainable Energy
Contributors: Kammer Hansen, K.
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Original language: English
Keywords: Fuel Cells and Hydrogen, Flue gas purification
DOIs:
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Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review
The Effect of a CGO Barrier Layer on the Performance of LSM/YSZ SOFC Cathodes

LSM/YSZ (Strontium substituted Lanthanum Manganite/Yttria Stabilised Zirconia) SOFC (Solid Oxide Fuel Cell) composite electrodes were fabricated with slurry spraying on both sides on either pure YSZ electrolyte foils or YSZ electrolyte foils with a CGO (Cerium-Gadolinium Oxide) barrier layer made by spin coating. Electrochemical impedance spectroscopy (EIS) was used to evaluate the performance of the LSM/YSZ composite electrodes. It was shown that the CGO barrier layer affects both the performance of the LSM/YSZ composite electrodes and the series resistance of the cells. This indicates that the cathode-electrolyte interface and the barrier layer-electrolyte interface have a large influence on the performance of LSM/YSZ composite electrodes.

The effect of A-site deficiency on the performance of La1-sFe0.4Ni0.6O3-delta cathodes

The effect of lowering the A-site stoichiometry of La-Fe-Ni based perovskite solid oxide fuel cell cathodes was investigated with electrochemical impedance spectroscopy on cone-shaped electrodes using a Ce0.9Gd0.1O1.95 electrolyte. It was shown that a lowering of the A-site stoichiometry lowers the amount of Ni in the perovskite phase, as powder XRD revealed that NiO was expelled from the perovskite lattice when the A-site stoichiometry was decreased. NiO inhibit the reduction of oxygen as the activity of a nominally A-site deficient La1-sFe0.4Ni0.6O3- perovskite was worse than the activity of the corresponding LaFe0.4+sNi0.6-sO3- perovskite without NiO. NiO is therefore poison for the reduction of oxygen at the cathode in a solid oxide fuel cell.
The Effect of H2S on the Performance of SOFCs using Methane Containing Fuel

In recent years, the interest for using biogas derived from biomass as fuel in solid oxide fuel cells (SOFCs) has increased. To maximise the biogas to electrical energy output, it is important to study the effects of the main biogas components (CH4 and CO2), minor ones and traces (e.g. H2S) on performance and durability of the SOFC. Single anode-supported SOFCs with Ni–Yttria-Stabilised-Zirconia (YSZ) anodes, YSZ electrolytes and lanthanum-strontium-manganite (LSM)–YSZ cathodes have been tested with a CH4–H2O–H2 fuel mixture at open circuit voltage (OCV) and 1 A cm–2 current load (850 °C). The cell performance was monitored with electric measurements and impedance spectroscopy. At OCV 2–24 ppm H2S were added to the fuel in 24h intervals. The reforming activity of the Ni-containing anode decreased rapidly when H2S was added to the fuel. This ultimately resulted in a lower production of fuel (H2 and CO) from CH4. Applying 1 A cm–2 current load, a maximum concentration of 7 ppm H2S was acceptable for a 24 h period.

Trends in Stability of Perovskite Oxides
Visualization of Electronically Conducting Paths in Solid Oxide Fuel Cells by Low-voltage SEM and Charge Contrast

General information
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Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Thydén, K. T. S., Ramos, T., Mogensen, M. B.
Publication date: 2010

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Visualization of Electronic Conducting Path In a Solid Oxide Fuel Cell by Low-voltage SEM and Charge Contrast

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Contributors: Thydén, K. T. S., Ramos, T., Mogensen, M. B.
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New Methods for Removal of Pollutants from Exhaust Gases

General information
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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.

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
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An EIS study of La2−aEuro parts per thousand x Sr x NiO4+ (delta) SOFC cathodes

La2−x Sr x NiO4+δ materials were investigated as cathodes for the electrochemical reduction of oxygen on a Ce1.9Gd0.1O1.95 (CGO10) electrolyte using cone-shaped electrodes together with electrochemical impedance spectroscopy. The area-specific resistance (ASR) of the La2−x Sr x NiO4+δ nickelates towards the reduction of oxygen is equal to the ASR of perovskites; however, it is not as low as for the best Fe–Co–based perovskites. The lowest ASR is found for the compound La1.75Sr0.25NiO4+δ with an ASR of 23.8 Ωcm2 measured on a cone-shaped electrode in air at 600 °C. It is suggested that difference in oxide ionic conductivity of the nickelates is the main cause for the different activity of the nickelates towards the electrochemical reduction of oxygen.

General information
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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Kammer Hansen, K.
Pages: 325-328
Publication date: 2009
Peer-reviewed: Yes
A-Site Deficient (Pr0.6Sr0.4)(1-s)Fe0.8Co0.2O3-delta Perovskites as Solid Oxide Fuel Cell Cathodes

Five A-site deficient (Pr0.6Sr0.4)1−sFe0.8Co0.2O3− perovskites (s=0.01, 0.05, 0.10, 0.15, and 0.20) were synthesized using the glycine-nitrate process. The perovskites were characterized with powder X-ray diffraction (XRD), dilatometry, four-point dc conductivity measurements, and electrochemical impedance spectroscopy using cone-shaped electrodes on a Ce0.9Gd0.1O1.95 electrolyte. XRD revealed that only the compounds with s=0.01 and 0.05 were of single phase. The other compounds contained an additional phase in the form of a Co–Fe spinel. The thermal expansion coefficient decreased systematically with an increase in s. The total conductivity followed the small polaron hopping process below a certain characteristic temperature. The total conductivity decreased with increasing s. It was likewise shown that the polarization resistance found a minimum for the compound with s=0.05, with a total area specific resistance more than 3 times lower than the weakly A-site deficient (Pr0.6Sr0.4)0.99Fe0.8Co0.2O3− perovskite. ©2009 The Electrochemical Society

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Aspects of Metal-YSZ Electrode Kinetics Studied using Model Electrodes

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Bibliographical note
Copyright The Electrochemical Society, Inc. [2009]. All rights reserved. Except as provided under U.S. copyright law, this work may not be reproduced, resold, distributed, or modified without the express permission of The Electrochemical Society (ECS).
Aspects of Metal-YSZ Electrode Kinetics Studied using Model Electrodes

The electrode kinetics of oxidation and reduction of H₂/H₂O and CO/CO₂ at the metal/yttria stabilized zirconia (YSZ) interface were studied using model metal wire electrodes contacting polished YSZ pellets. The intent was to probe the reaction mechanisms by comparing the same reactions using different metals (Ag, Au, Cu, Ni, Pd, and Pt) under identical conditions relevant to fuel cell and electrolysis cell operation (e.g. including 50% H₂/H₂O and 50% CO/CO₂). Impedance spectra were measured at open-circuit voltage and under polarization, and polarization sweeps were performed. The gas composition and temperature were varied to examine how the electrochemical measurements varied, to facilitate identifying the electrode rate-limiting processes. Possible mechanisms that may explain these and other details are discussed.

Carbon dioxide electrolysis for production of synthesis gas in solid oxide electrolysis cells

General information
Characterization of MgMnxFe2-xO4 as a possible cathode material for electrochemical reduction of NOx

Spinel-type oxides of MgMnxFe2-xO4, x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, were synthesized as a solid state reaction and characterized with dilatometry and resistivity measurements up to 1000 °C. Results showed a general decrease of the linear expansion and an increase in conductivity as a function of the Mn content. Point electrodes were analyzed from 300 to 600 °C in a pseudo-three-electrode setup in 1% NO, 1% NO2, and 10% O2 using cyclic voltammetry. The activities in O2 were in general very low whereas the activities in NO were slightly higher. The activities in NO2 were for all materials much higher than the activities in O2. Even though Mn tends to decrease the activity of the materials, current ratios of have relatively high values in both NO and NO2.

General information

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Contributors: Bræstrup, F. R., Kammer Hansen, K.
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DOI:s 10.1007/s10800-009-9923-1
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Research output: Contribution to journal → Journal article – Annual report year: 2009 → Research → peer-review

Chromium poisoning of LSM/YSZ and LSCF/CGO composite cathodes

An electrochemical study of SOFC cathode degradation, due to poisoning by chromium oxide vapours, was performed applying 3-electrode set-ups. The cathode materials comprised LSM/YSZ and LSCF/CGO composites, whereas the electrolyte material was 8YSZ. The degradation of the cathode performance was investigated as a function of time under a current load of 0.2 or 0.4 A cm-2 and in the presence of Cr2O3 at 850 and 750 °C in air, dry or water saturated at room temperature, and compared to that of non-Cr exposed reference specimens tested under, otherwise, the same conditions. This involved continuous logging of the DC current, and the voltage between the reference electrode and the working electrode in the 3-electrode set-up combined with frequent AC impedance measurements under current load which would allow the deduction of the cathode polarisation resistance (Rp). The duration of the tests ranged from 300 to 2,970 h. Both LSM/YSZ and LSCF/CGO cathodes were sensitive to chromium poisoning; LSCF/CGO cathodes to a lesser extent than LSM/YSZ. Humid air aggravated the degradation of the cathode performance. Post-mortem electron microscopic investigations revealed several Cr-containing compounds filling up the microstructure of the cathodes.

General information
Comparison of the Degradation of the Polarisation Resistance of Symmetrical LSM-YSZ cells, with Anode Supported Ni-YSZ/YSZ/LSM-YSZ SOFCs

Impedance spectra of a symmetrical cell with SOFC cathodes (LSM-YSZ/YSZ/LSM-YSZ) and an anode supported planar SOFC (Ni-YSZ/YSZ/LSM-YSZ) were collected at OCV at 650°C in air (cathode) and humidified (4%) hydrogen (anode), over 155 hours. The impedance was affected by degradation over time in the same frequency range for both cells (~10 Hz), possibly indicating that the same physical process was affected in both types of cell. However, deconvolution of the impedance data was not straightforward. When n-values of the constant phase elements in the otherwise identical equivalent circuit for the full cell were changed slightly, very different results were obtained, showing the high sensitivity of the fitting procedure. Therefore, the equivalent circuit applied should be refined further, requiring comparison of impedance data of the cells at higher temperature (750, 850°C).

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Peer-reviewed: Yes

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Scopus rating (2009): SJR 0.242 SNIP 0.276
Original language: English
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen
Electronic versions:
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Comparison of the Degradation of the Polarization Resistance of Symmetrical LSM-YSZ Cells, with Anode Supported Ni-YSZ/YSZ/LSM-YSZ SOFCs

General information
Publication status: Published
Contributors: Torres da Silva, I. M., Nielsen, J., Hjelm, J., Mogensen, M. B.
Pages: Abstract 1508
Publication date: 2009

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Bibliographical note
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Defect structure, electronic conductivity and expansion properties of LaSrCoNiO₃

General information
Publication status: Published
Contributors: Hjalmarsson, P., Søgaard, M., Mogensen, M. B.
Publication date: 2009
Peer-reviewed: Yes
Event: Abstract from American Ceramic Society conference, Dayton.
Electronic versions:
Abstract_Dayton.pdf

Development of Planar Metal Supported SOFC with Novel Cermet Anode

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemical Evaluation, Microstructures and Interfaces, Electroceramics, Electrochemistry
Pages: Abstract 1441
Publication date: 2009

Host publication information
Title of host publication: Meeting Abstracts - Electrochemical Society
Publisher: The Electrochemical Society
Electronic versions:
Johan.pdf
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.

Dimensional behavior of Ni-YSZ composites during redox cycling

The dimensional behavior of Ni-yttria-stabilized zirconia (YSZ) cermets during redox cycling was tested in dilatometry within the temperature range 600-1000 degrees C. The effect of humidity oil redox stability was investigated at intermediate and low temperatures. We show that both the sintering of nickel depending on temperature of the initial reduction and the operating conditions, and the temperature of reoxidation are very important for the size of the dimensional change. Cumulative redox strain (CRS) is shown to be correlated with temperature. Measured maximum CRS after three redox cycles varies within 0.25-3.2% dL/L in dry gas and respective temperature range of 600-1000 degrees C. A high degree of redox reversibility was reached at low temperature. however, reversibility is lost at elevated temperatures. We found that at 850 degrees C, 6% steam and a very high p(H2O)/p(H2) ratio is detrimental for redox stability, whereas at 600 degrees C no negative effect was observed. Pre-reduction at 1100 instead of 800 degrees C more than doubled redox strain on reoxidation at 800 degrees C. For samples similarly pre-reduced at 1000 degrees C, lowering the reoxidation temperature from 1000 to 750 degrees C or below reduces the redox strain to less than half. (C)
Electrical Properties of Fuel Cell Materials

General information
Publication status: Published
Contributors: Pihlatie, M., Kaiser, A., Larsen, P. H., Mogensen, M. B.
Pages: B322-B329
Publication date: 2009
Peer-reviewed: Yes

Publication information
Journal: Journal of The Electrochemical Society
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Scopus rating (2009): SJR 1.442 SNIP 1.259
Web of Science (2009): Indexed yes
Original language: English
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen
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Source: orbit
Source ID: 232610
Research output: Contribution to journal › Journal article – Annual report year: 2009 › Research › peer-review

Electrochemical behaviour of \( (\text{La}_{1-x}\text{Sr}_x)\text{Co}_{1-y}\text{Ni}_y\text{O}_3\) as porous SOFC cathodes

This paper shows that storage at room temperature and ambient atmosphere appears to affect the polarisation resistance significantly and RP decreased initially with storage time. This improvement was more pronounced when stored in moisturised air. The performance was, however, also found to decrease when stored for sufficiently long periods. The absolute values of the electrode response of these materials are very difficult to reproduce and the performance appears to be largely dependent on the manufacturing process of the powder or the electrode itself. In spite of this, the electrode behaviours exhibited similar patterns with respect to the dependence on T and P\(\text{O}_2\). An increase in polarisation resistance with time at SOFC operating conditions was observed, which was related exclusively to the electrode reaction kinetics and not to oxygen concentration polarisation. It was also found to be higher when measured in moisturised air.

General information
Publication status: Published
Electrochemical Characterisation of SOFC Anodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Ramos, T., Mogensen, M. B.
Pages: Abstract 1399
Publication date: 2009

Host publication information
Title of host publication: Meeting Abstracts - Electrochemical Society
Publisher: The Electrochemical Society
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Ramos.pdf

Bibliographical note
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Source: orbit
Source ID: 264297
Research output: Chapter in Book/Report/Conference proceeding > Conference abstract in proceedings – Annual report year: 2009 > Research > peer-review

Electrochemical characterization and redox behavior of Nb-doped SrTiO$_3$
Sr-vacancy compensated Nb-doped SrTiO$_3$ with the nominal composition Sr0.94Ti0.9Nb0.1O3 has been evaluated as a solid oxide fuel cell (SOFC) anode material in terms of redox stability and electrochemical properties. Sr0.94Ti0.9Nb0.1O3 has been synthesized with a recently developed modified glycine-nitrate process. The phase purity and redox behavior have been analyzed with XRD and TGA. The electrochemical properties of Sr0.94Ti0.9Nb0.1O3 and a composite electrode of Sr0.94Ti0.9Nb0.1O3/YSZ have been investigated by electrochemical impedance spectroscopy (EIS) on cone shaped electrodes and on electrodes in a symmetrical cell configuration. The experiments indicated that the Nb-doped SrTiO$_3$ electrodes were redox stable and showed a potential ability to be used as a part of a SOFC anode. The electrochemical activity appeared to be governed by the concentration of defect species (especially Ti$^{3+}$ and V-0(++) in the vicinity of the triple phase boundaries. However, the electrocatalytic activity of the materials was not sufficient and it needs to be improved if Nb-doped SrTiO$_3$ based materials are to be realized as SOFC anodes. (C) 2008 Elsevier B.V. All rights reserved.

General information
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Electrochemical impedance spectroscopy as diagnostic tool

General information
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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Jensen, S. H., Hjelm, J., Hagen, A., Mogensen, M. B.
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Publication date: 2009

Host publication information
Title of host publication: Handbook of Fuel Cells – Fundamentals, Technology and Applications
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Publisher: Wiley
Editors: Vielstich, W., Gasteiger, H., Yokokawa, H.
ISBN (Print): 978-0-470-72311-1
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen
Source: orbit
Source ID: 236770

Electrochemical reduction of NO on La$_2$-$x$Sr$_x$NiO$_4$ based electrodes
The series La$_2$-$x$Sr$_x$NiO$_4$ ($x=0.0$, 0.05, 0.15, 0.25, 0.35, and 1.0) was tested for functionality as electrode materials for direct electrochemical reduction of NO. The materials were tested using cyclic voltammetry in 1% NO and 10% O$_2$ in Ar on a cone-shaped electrode. The best materials for the electrochemical reduction of NO are La$_2$NiO$_4$ and LaSrNiO$_4$, which have current densities for NO reduction 1.82 and 7.09 times higher, respectively, than for O$_2$ at 400 °C. Increasing the temperature decreased the ability to reduce NO before O$_2$ while the activity increased. The adsorbed species during direct decomposition was attempted, clarified using X-ray absorption near-edge structure experiments and thermogravimetry, but no conclusive results were obtained.

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Simonsen, V. L. E., Nørskov, L., Hagen, A., Kammer Hansen, K.
Pages: 1529-1534
Publication date: 2009
Peer-reviewed: Yes

Publication information
Electrolysis of carbon dioxide in Solid Oxide Electrolysis Cells

Carbon dioxide electrolysis was studied in Ni/YSZ electrode supported Solid Oxide Electrolysis Cells (SOECs) consisting of a Ni-YSZ support, a Ni-YSZ electrode layer, a YSZ electrolyte, and a LSM-YSZ O2 electrode (YSZ = Yttria Stabilized Zirconia). The results of this study show that long term CO2 electrolysis is possible in SOECs with nickel electrodes. The passivation rate of the SOEC was between 0.22 and 0.44 mV h⁻¹ when operated in mixtures of CO2/CO = 70/30 or CO2/CO = 98/02 (industrial grade) at 850 °C and current densities between −0.25 and −0.50 A cm⁻². The passivation rate was independent of the current density and irreversible when operated at conditions that would oxidise carbon. This clearly shows that the passivation was not caused by coke formation. On the other hand, the passivation was partly reversible when introducing hydrogen. The passivation may be a consequence of impurities in the gas stream, most likely sulphur, adsorbing on some specific nickel sites in the cathode of the SOEC. Activation can be carried out by hydrogen reacting with adsorbed sulphur to form the volatile compound H2S. Because adsorption of sulphur is site specific, only a part of the nickel sites were passivated and long-time operation of CO2 electrolysis in these Ni/YSZ electrode supported Solid Oxide Electrolysis Cells seems therefore feasible.

General information

Publication status: Published
Contributors: Ebbesen, S., Mogensen, M. B.
Pages: 349-358
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Peer-reviewed: Yes

Publication information

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Ratings:
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.105 SNIP 1.776
Web of Science (2009): Indexed yes
Original language: English
Keywords: Fuel Cells and hydrogen, Elektrolyse, Electrolysis
DOIs:
10.1016/j.jpowsour.2009.02.093
Source: orbit
Source ID: 247170
Research output: Contribution to journal › Journal article – Annual report year: 2009 › Research › peer-review

Electromotive Potential Distribution and Electronic Leak Currents in Working YSZ Based SOCs

The size of electronic leak currents through the YSZ electrolyte of solid oxide cells have been calculated using basic solid state electrochemical relations and literature data. The distribution of the electromotive potential, of Galvani potential, of concentration of electrons, e, and electron holes, h, was also calculated as these parameters are the basis for the understanding of the electronic conductivity that causes the electronic leak currents. The results are illustrated with examples. The effects of electrolyte thickness, temperature and cell voltage on the electronic leak current density are reported.
Impact of impurities and interface reaction on electrochemical activity

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Microstructures and Interfaces
Contributors: Mogensen, M. B., Hansen, K. V.
Publication date: 2009

Host publication information
Title of host publication: Handbook of Fuel Cells - Fundamentals, Technology and Applications. Vol. 5: Advances in Electrocatalysis, Materials, Diagnostics and Durability
Volume: Chapter 36
Publisher: Wiley-Blackwell
ISBN (Print): 978-0-470-72311-1
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen
Source: orbit
Source ID: 255364

Kan vi få CO2-neutral benzin?

General information
Publication status: Published
Contributors: Ebbesen, S., Jensen, S. H., Smith, A., Mogensen, M. B.
Pages: 28-30
Publication date: 2009
Peer-reviewed: Unknown

Publication information
Journal: Dansk Kemi
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Original language: Danish
Keywords: Fuel Cells and hydrogen
Source: orbit
Source ID: 253841
Research output: Contribution to journal – Journal article – Annual report year: 2009 – Communication

Mechanical properties of NiO/Ni-YSZ composites depending on temperature, porosity and redox cycling

The Impulse Excitation Technique (IET) was used to determine the elastic modulus and specific damping of different Ni/NiO-YSZ composites suitable for use in solid oxide fuel cells (SOFC). The porosity of the as-sintered samples varied from 9 to 38% and that of the reduced ones from 31 to 52%. For all samples a linear relation between Young's modulus...
and porosity was found. The temperature dependency of the mechanical properties of both as-sintered and reduced composites was investigated by IET up to 1200 degrees C. In the as-sintered state, first an increase and peak of stiffness coinciding with the Neel temperature, 250 degrees C, of NiO was observed. Above this temperature, a linear decrease occurred. Specific damping showed a peak at 170-180 degrees C and increased above ca. 1000 degrees C in NiO-YSZ. In the reduced state the elastic modulus decreased linearly with temperature; specific damping increased above ca. 600 degrees C and was found to be very dependent on microstructure. Damage caused by redox cycling degraded the elastic properties of the composites. Degradation started linearly from 0.5 to 0.6% redox strain leading to macroscopic sample failures at about 2.5% dL/L-o. A simple continuum elastic damage model was fitted to the degradation data. (C) 2008 Elsevier Ltd. All rights reserved.

**General information**
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Electrochemistry
Contributors: Pihlatie, M., Kaiser, A., Mogensen, M. B.
Pages: 1657-1664
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Peer-reviewed: Yes

**Publication information**
Journal: Journal of the European Ceramic Society
Volume: 29
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ISSN (Print): 0955-2219
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BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.374 SNIP 1.705
Web of Science (2009): Indexed yes
Original language: English
Keywords: Fuel Cells and hydrogen, Ceramic Membranes
DOI:
10.1016/j.jeurceramsoc.2008.10.017
Source: orbit
Source ID: 233770

**Nano-scale in SOFC electrodes**

**General information**
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Mogensen, M. B.
Publication date: 2009
Peer-reviewed: No
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen
Source: orbit
Source ID: 255421
Research output: Contribution to conference – Conference abstract for conference – Annual report year: 2009 – Research

**On the H2/H2O/Ni/SZ and the CO2/CO/Ni/SZ Electrode Kinetics**

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Publication date: 2009

**Host publication information**
Title of host publication: Program and Extended Abstracts
Keywords: Fuel Cells and hydrogen, Electrolysis
Source: orbit
Oxygen transport properties of dense and porous (La\(_{0.8}\)Sr\(_{0.2}\))\(_{0.99}\)Co\(_{0.8}\)Ni\(_{0.2}\)O\(_{3-\delta}\)

We have determined \(k_{\text{ex}}\) and \(D_{\text{chem}}\) for (La\(_{0.8}\)Sr\(_{0.2}\))\(_{0.99}\)Co\(_{0.8}\)Ni\(_{0.2}\)O\(_{3-\delta}\) by the use of electrical conductivity relaxation on a dense sample and by applying the ALS model to measured AC impedance spectrum on a porous electrode. Extracting \(k_{\text{ex}}\) and \(D_{\text{chem}}\) from the methods resulted in comparable values. \(k_{\text{ex}}\) and \(D_{\text{chem}}\) also agreed well with literature values on La\(_{0.8}\)Sr\(_{0.2}\)CoO\(_{3-\delta}\), indicating that nickel substitution does not change the oxygen transport properties. \(k_{\text{ex}}\) of the porous sample was further found to decrease with a five times higher rate than \(D_{\text{chem}}\) when measured by using an Electrochemical Impedance Spectroscopy (EIS) over several days.

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Hjalmarsson, P., Søgaard, M., Mogensen, M. B.
Pages: 1290-1297
Publication date: 2009
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Publication information
Journal: Solid State Ionics
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Scopus rating (2009): SJR 1.508 SNIP 1.48
Web of Science (2009): Indexed yes
Original language: English
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen
DOIs: 10.1016/j.ssi.2009.07.012
Source: orbit
Source ID: 255252
Research output: Contribution to journal › Journal article – Annual report year: 2009 › Research › peer-review

Processing and characterization of porous electrochemical cells for flue gas purification

In the present work, porous electrode materials lanthanum strontium manganate (LSM)-gadolinium-doped cerium oxide (CGO) and electrochemical cells LSM-CGO + CGO were fabricated via the processes of slurry preparation, tape casting and lamination, and sintering. Graphite, wheat starch, and polyamide powders were used as pore formers, respectively, in order to investigate their effects on shrinkage, flow rate, porosity, and average pore size of the sintered samples. The observation from scanning electronic microscope (SEM) revealed different microstructures caused by different pore formers. Porous, flat, and crack-free electrochemical cells were successfully achieved using the present ceramic processing route. The produced cells could potentially be used for flue gas purification.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: He, Z., Andersen, K. B., Keel, L., Nygaard, F. B., Menon, M., Kammer Hansen, K.
Pages: 427-431
Publication date: 2009
Peer-reviewed: Yes

Publication information
Journal: Ionics
Volume: 15
Issue number: 4
ISSN (Print): 0947-7047
Ratings:
BFI (2009): BFI-level 1
Production of Hydrogen and Synthesis Gas by High Temperature Electrolysis

Electrolysis of steam and co-electrolysis of steam and carbon dioxide was studied in stacks composed of Ni/YSZ electrode supported Solid Oxide Electrolysis Cells. The results of this study show that long term electrolysis is feasible in these solid oxide electrolysis stacks. The degradation of the electrolysis cells was found to be influenced by the adsorption of impurities from the gasses, whereas the application of chromium containing interconnect plates and glass sealings do not seem to influence the durability. Cleaning the inlet gasses to the Ni/YSZ electrode resulted in operation without any long term degradation, and may therefore be a solution for operating these Ni/YSZ based solid oxide electrolysis stacks without any long term cell stack degradation.

Production of Synthetic Fuels by Co-Electrolysis of Steam and Carbon Dioxide

Co-electrolysis of H2O and CO2 was studied in solid oxide cells (SOCs) supported by nickel-/yttria-stabilized zirconia (Ni/YSZ) electrode. Polarization characterization indicates that electrochemical reduction of both CO2 and H2O occurs during co-electrolysis. In parallel with the electrochemical reactions, the equilibrium of the water-gas shift reaction is reached, and moreover, CO is produced via the water-gas shift reaction. The degradation observed when performing co-electrolysis in these SOCs occurs mainly at the Ni/YSZ cathode and may be a consequence of impurities in the gas stream, adsorbing on active sites in the SOC. The low degradation is most likely acceptable for long-time operation.
Realising Reliable, Durable, Energy Efficient and Cost Effective SOFC Systems (Real-SOFC)

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Jülich Research Centre
Contributors: Holtappels, P., Steinberger-Wilckens, R.
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Journal: Fuel Cells
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Source: orbit
Source ID: 257135
Research output: Contribution to journal › Editorial – Annual report year: 2009 › Research › peer-review

Redox stability of SOFC: Thermal analysis of Ni-YSZ composites
A re-oxidation of a Ni-based SOFC can seriously damage the cells. Important aspects of this thermomechanical instability are reduction–oxidation kinetics and the dimensional behaviour of the Ni–YSZ composites. These were investigated in the temperature range of 600–1000 °C and different combinations of reduction and oxidation temperatures. Automated temperature and gas change programmes were implemented in thermogravimetry and identically repeated using a high precision dilatometer to show the dimensional behaviour of the cermets simultaneously with the Degree of Oxidation (DoO) as a function of time during redox cycling. The activation energy for reduction was 84.4 kJ/mol and the kinetics was largely linear. Different kinetic models were fitted to the reduction data; the best agreement was found using the Avrami equation. On the re-oxidation, initially linear kinetics was observed, followed by a period of parabolic kinetics slowing down to logarithmic towards full DoO. The shifts in the kinetic shape with time depended on the temperature and DoO. The rate constants for oxidation were fitted to the data. The BET surface area of the cermets after different reduction and oxidation treatments was measured and show decrease of surface area with increasing reduction temperature and no significant differences in the surface area depending on the re-oxidation temperature in the range of 600–1000 °C.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Electrochemistry
Contributors: Pihlatie, M., Kaiser, A., Mogensen, M. B.
Scanning Probe Microscopy at 650 °C in Air

The controlled atmosphere high temperature scanning probe microscope was designed to study the electrical properties of surfaces at elevated temperatures by using the probe as an electrode. The capability of a simultaneous acquisition of topographical and electrical data for the same surface area at 650°C is demonstrated on several samples.

General information
Publication status: Published
Organisations: Microstructures and Interfaces, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Physical Chemistry, Department of Chemistry, Electrochemistry, University of Oldenburg
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Publication date: 2009
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Publication information
Journal: Electrochemical and Solid-State Letters
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Scopus rating (2009): SJR 1.231 SNIP 1.003
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Source ID: 248720
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SOEC potential economics, peak shaving

General information
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Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Jensen, S. H.
Publication date: 2009
Peer-reviewed: No
Event: Abstract from HyFC Academy Workshop, Risø, Denmark.
Keywords: Fuel Cells and hydrogen, Electrolysis
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Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2009 › Research

SOEC - Status, problems and perspectives

General information
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Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Mogensen, M. B.
Publication date: 2009
Peer-reviewed: No
Event: Abstract from 3rd International Workshop on HTE, Karlsruhe (DE), 9-10 June, .
Keywords: Fuel Cells and hydrogen, Electrolysis
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Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2009 › Research

Status of high temperature electrolysers

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Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Mogensen, M. B.
Publication date: 2009
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Source: orbit
Source ID: 255426
Research output: Contribution to conference › Paper – Annual report year: 2009 › Research

Strontium-Doped Lanthanum Manganite Films Prepared by Magnetic Deposition
Deposition of La0.85Sr0.15MnO3 (LSM) films from suspensions using a magnetic field was found to be a cheap and quick technique. Ninety weight percent of the particles present in the suspensions were deposited within the first minute of the deposition, and the thickness of the film varied linearly with the concentration of the suspension. Deposition phenomena were explained by modeling the magnetic flux in the deposition cell. Particles aligned with the flux lines, forming chains of LSM particles that, upon sintering, resulted in the formation of porous films with long chains of LSM grains.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Menon, M., Larsen, C., Andersen, K. B.
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Publication date: 2009
Peer-reviewed: Yes

Publication information
Journal: Journal of the American Ceramic Society
Sustainable production of synthesis gas via electrolysis

Testing and improving the redox stability of Ni-based solid oxide fuel cells
The effect of H2S on the performance of Ni-YSZ anodes in solid oxide fuel cells

Biomass-derived fuel, e.g. biogas, is a potential fuel for solid oxide fuel cells (SOFCs). At operating temperature (850 °C) reforming of the carbon-containing biogas takes place over the Ni-containing anode. However, impurities in the biogas, e.g. H2S, can poison both the reforming and the electrochemical activity of the anode. Tests of single anode-supported planar SOFCs were carried out in the presence of H2S under current load at 850 °C. The cell voltage dropped as we periodically added 2–100 ppm H2S to an H2-containing fuel in 24 h intervals, but it regenerated to the initial value after we turned off the H2S. Evaluation of the changes of the cell voltage suggests that saturation coverage was reached at approximately 40 ppm H2S. A front-like movement of S-poisoning over the anode was seen by monitoring the in-plane voltage in the anode. Furthermore, impedance spectra showed that mainly the polarization resistance increased when adding H2S. These changes in resistance were found to happen at 1212 Hz, which is related to reactions at the anode-electrolyte interface. These findings can be used to identify S-related effects on the performance, when an SOFC is fuelled with biogas or other fuels with H2S impurities and thus help in the development of more sulfur tolerant SOFCs.

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Contributors: Rasmussen, J. F. B., Hagen, A.
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Web of Science (2009): Indexed yes
Original language: English
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen

The effect of nanostructures in solid oxide electrodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Publication date: 2009
Peer-reviewed: No
Keywords: Solid Oxide Fuel Cells, Fuel Cells and hydrogen

The effect of nanostructures in solid oxide electrodes
The integrated project SOFC600 development of low-temperature SOFC
The Integrated Project SOFC600 unites 21 partners jointly working on the research and development of SOFC stack components for operation at 600°C. The project is funded by the European Commission within the 6th Framework Programme. Low-temperature operation is considered essential for achieving commercial targets for lifetime and costs. This paper gives an overview of the activities in the project and of the main overall results achieved up to now.

The NiFe2O4-MgFe2O4 series as electrode materials for electrochemical reduction of NOx
Solid solutions of spinel-type oxides with the composition (x=0.0, 0.3, 0.5, 0.6, 1.0) were prepared with the glycine-nitrate combustion synthesis (x=0.0, 0.3, 0.5, 0.6) and the citric-acid combustion synthesis (x=1.0). The oxides were used as electrode materials in a pseudo-three-electrode setup in the temperature range of 400–600 °C. Cyclic voltammetry and electrochemical impedance spectroscopy were used to characterize the electrochemical behavior in 1% NO and 10% O2. Measurements show that NiFe2O4 has relatively high cathodic activity in both NO and O2, whereas MgFe2O4 shows much higher activity in NO compared to O2. MgFe2O4 was also measured with cyclic voltammetry in 1% NO2 and different gas mixtures of NO and O2 at 300 and 400 °C. Results show that the cathodic activities (~0.6 V) are relatively high with current ratios, ranging from 10.1–167.7 and with a maximum at 400 °C. Dilatometry measurements were performed on the materials in air up to 1,000 °C, and they showed that the Curie temperature could be detected for all samples. Four-point DC resistivity measurements at elevated temperatures show that Ni0.4Mg0.6Fe2O4 has the highest conductivity, whereas Ni0.7Mg0.3Fe2O4 and NiFe2O4 have the highest conductivity at lower temperatures.
Three-phase-boundary dynamics at the Ni/ScYSZ interface

Chronoamperometry using a three-electrode cell configuration was undertaken with a nickel point-electrode acting as the working electrode on a polished ScYSZ electrolyte in a hydrogen atmosphere at 750–850 °C. High anodic overpotentials resulted in the occurrence of distinct sawtooth oscillation patterns in the measured current signal. The current oscillations indicated that a dynamic electrode process was taking place. Decreasing the water content in the measurement atmosphere as well as lowering the applied anodic overpotential had the effect of lowering the frequency and the amplitude of the current oscillations. A mechanism accounting for the observed phenomena and possible implications for solid oxide fuel cell operation are presented.
Effects of trace elements at the Ni/ScYSZ interface in a model solid oxide fuel cell anode

Two ScYSZ electrolytes with different impurity levels were evaluated by electrochemical impedance spectroscopy using a nickel point electrode setup. The nickel electrodes showed lower electrode polarization resistances on the pure electrolyte than on the impure electrolyte. Time-of-flight secondary ion mass spectrometry was used to evaluate the electrode/electrolyte interfaces. Stronger signals from silica impurities in the electrode/electrolyte interface, relative to the electrolyte/gas interface, were found on the impure electrolyte than on the pure electrolyte. (C) 2007 Elsevier B.V. All rights reserved.

Aerobic Oxidation of Alcohols over Gold Catalysts: Role of Acid and Base

Gold nanoparticles are deposited on potassium titanate nanowires and used as heterogeneous catalysts in the aerobic oxidation of benzyl alcohol in methanol to methyl benzoate at ambient conditions. The presence of a catalytic amount of base promotes the reaction and the formation of free benzoic acid during the reaction poisons the catalyst. The activity however, of the catalyst can be restored again by addition of base.
Assessment of the cathode contribution to the degradation of anode-supported solid oxide fuel cells

The degradation of anode-supported cells was studied over 1500 h as a function of cell polarization either in air or oxygen on the cathode side. Based on impedance analysis, contributions of the anode and cathode to the increase of total resistance were assigned. Accordingly, the degradation rates of the cathode were strongly dependent on the pO(2). Microstructural analysis of the cathode/electrolyte interface carried out after removal of the cathode showed craters on the electrolyte surface where the lanthanum strontium manganite (LSM) particles had been located. The changes of shape and size of these craters observed after testing correlated with the cell voltage degradation rates. The results can be interpreted in terms of element redistribution at the cathode/electrolyte interface and formation of foreign phases giving rise to a weakening of local contact points of the LSM cathode and yttria-stabilized zirconia electrolyte and consequently a reduced three-phase boundary length. (C) 2008 The Electrochemical Society.
Characterisation of the Ni/ScYSZ interface in a model solid oxide fuel cell anode
A nickel point electrode setup was used as a model of an SOFC anode on three slightly different electrolytes of zirconia stabilised by co-doping with scandia and yttria. The effect of electrolyte impurities on the electrode polarisation resistance was investigated by correlating electrochemical impedance spectroscopy data with time-of-flight secondary ion mass spectrometry, scanning electron microscopy and atomic force microscopy data. A semi-quantitative analysis of the electrolyte surfaces showed that the levels of surface impurities inside the electrode/electrolyte interface in close proximity to the three phase boundary have a large effect on the electrode polarisation resistance.

Chromium poisoning evaluation based on symmetrical cathode cell tests
A nickel point electrode setup was used as a model of an SOFC anode on three slightly different electrolytes of zirconia stabilised by co-doping with scandia and yttria. The effect of electrolyte impurities on the electrode polarisation resistance was investigated by correlating electrochemical impedance spectroscopy data with time-of-flight secondary ion mass spectrometry, scanning electron microscopy and atomic force microscopy data. A semi-quantitative analysis of the electrolyte surfaces showed that the levels of surface impurities inside the electrode/electrolyte interface in close proximity to the three phase boundary have a large effect on the electrode polarisation resistance.
Chromium poisoning of LSC cathodes using symmetrical cells at 600 deg. C

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Source: orbit
Source ID: 231997
Research output: Contribution to conference › Paper – Annual report year: 2008 › Research

Controlled atmosphere high temperature SPM for electrochemical measurements

General information
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Organisations: Microstructures and Interfaces, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry, DME - Danish Micro Engineering A/S
Contributors: Hansen, K. V., Sander, C., Koch, S., Mogensen, M. B.
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Web of Science (2008): Indexed yes
Original language: English
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Source ID: 223432
Research output: Contribution to journal › Conference article – Annual report year: 2008 › Research › peer-review

Defect and electrical transport properties of Nb-doped SrTiO3
This study reports the defect and electrical transport properties of Nb-doped SrTiO3. Samples with various A/B-ratios were synthesized by a modified glycine-nitrate combustion process and evaluated as a constituent in a SOFC anode. The phase purity and defect structure of the materials have been analyzed with SEM, XRD, TGA, and XANES. The electrical conductivity of Nb-doped strontium titanate (Sr0.94Ti0.9Nb0.1O3 - sintered in 9% H-2/N-2 at 1400 degrees C for 12 h) decreased with increasing temperature and showed a phonon scattering conduction mechanism with (sigma>120 S/cm at 1000 degrees C in 9% H-2/N-2). The results were in agreement with the defect chemistry model of donor-doped SrTiO3 where the charge compensation changes from Sr vacancy compensation to the electronic type when samples are sintered in reducing atmosphere. XANES in combination with TGA indicated that Ti is the only species that is reduced to a lower oxidation state (from Ti4+ to Ti3+). The pre-edge fine structure (PEFS) from the XANES results indicated that Nb improved the overlap of the Ti atomic orbitals and thereby provided one more explanation for the positive effect of Nb on the electronic conductivity of Nb-doped SrTiO3. (C) 2008 Elsevier B.V. All rights reserved.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry, Lund University
Contributors: Blennow Tullmar, P., Hagen, A., Kammer Hansen, K., Wallenberg, L. R., Mogensen, M. B.
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Publication date: 2008
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Degradation mechanisms on LSM/YSZ electrodes

General information
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Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Microstructures and Interfaces, Electrochemistry
Contributors: Hendriksen, P. V., Liu, Y., Chen, M., Barfod, R., Poulsen, F. W., Hagen, A.
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Degradation Study of SOFCs Under Cycling Current Load Conditions

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Haldor Topsoe AS
Contributors: Hagen, A., Barfod, R., Hendriksen, P. V.
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Publisher: European solid oxide fuel cell forum
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Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 2008 > Research

Effects of A/B-ratio in strontium doped lanthanum cobaltite

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Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Department of Mechanical Engineering, Electrochemistry
Contributors: Segaard, M., Lybye, D., Hendriksen, P. V., Jacobsen, T., Mogensen, M. B.
Pages: 382-395
Publication date: 2008

Host publication information
Title of host publication: Ionic and mixed conducting ceramics V
Publisher: The Electrochemical Society
Editors: Ramanarayanan, T., Mogensen, M. B., Yokokawa, H.
Electro- and photochemical switching of dithienylethene self-assembled monolayers on gold electrodes

The photochemical and electrochemical properties of self-assembled monolayers (SAM) of three structurally distinct hexahydro- and hexafluoro-dithienylcyclopentene-based photochromic switches on gold electrodes are reported. The photochemical and electrochemical switching between the open and closed forms of the dithienylethene SAMs is examined and found to be sensitive to the molecular structure of the switch. For the three dithienylethenes, the electrochemical behavior with respect to electrochemical ring opening/closing is retained in the SAMs. In contrast, a marked dependence on the nature of the anchoring group is observed upon immobilization in terms of the retention of the photochemical properties observed in solution. For the meta-thiophenol anchor both photochemical ring opening and closing are observed in the SAM, while for the thiethyl-thiol-anchored switches the photochemically properties are changed markedly compared with those observed in solution. The stability of the monolayers toward desorption following photochemical and electrochemical switching is examined through electrochemistry and X-ray photoelectron spectroscopy.

General information
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Contributors: Browne, W., Kudernac, T., Katsonis, N., Areephong, J., Hjelm, J., Feringa, B.
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Original language: English
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Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

Electrochemical cell for removing NOx and soot from diesel exhaust

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Andersen, K. B., He, Z., Werchmeister, R. M. L., Keel, L., Nygaard, F. B., Menon, M., Kammer Hansen, K.
Pages: 169-169
Publication date: 2008

Host publication information
Title of host publication: Book of abstracts
Publisher: American Ceramic Society
Source: orbit
Source ID: 232442
Research output: Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report year: 2008 › Research
Electrochemical Characterization of Planar Anode Supported SOFC with Strontium-Doped Lanthanum Cobalt Oxide Cathodes

General information
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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
Contributors: Hjelm, J., Søgaard, M., Knibbe, R., Hagen, A., Mogensen, M. B.
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Source: orbit
Source ID: 232660
Research output: Contribution to journal › Conference article – Annual report year: 2008 › Research › peer-review

Electrochemical performance and degradation of (La0.6Sr0.4)0.99CoO3−δ as porous SOFC-cathode
This paper shows that measured impedance in porous (La0.6Sr0.4)(0.99)CoO3-delta cathodes can be dependent on both gas diffusion and electrode kinetics at temperatures above 700 degrees C or below ambient pO(2)S if electrode kinetics are fast. The reaction mechanism is discussed on the basis of measured temperature- and pO(2)-dependences. The degradation was found to be related exclusively to the electrode kinetics and measured about 0.5-1.5 m Omega cm(2) days(-1) depending on temperature with a higher rate measured in moisturised air. We speculate on degradation mechanism that involves formation of strontium hydroxides at catalytically active oxygen vacancy sites at the electrode surface. (C) 2007 Elsevier B.V All rights reserved.

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
Contributors: Hjalmarsson, P., Mogensen, M. B., Søgaard, M.
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Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

Electrochemical reduction of NO and O2 on La2-xSrxCuO4-based electrodes
Evaluation of LSF based SOFC Cathodes using Cone-shaped Electrodes

Seven La$_{1-x}$Sr$_x$FeO$_{3-delta}$ ($x = 0, 0.05, 0.15, 0.25, 0.35, 0.50, 0.70$) based perovskites were synthesized using the glycine-nitrate method. The La$_{1-x}$Sr$_x$FeO$_{3-delta}$ compounds were characterized with powder X-ray diffraction and electrochemical impedance spectroscopy on cone-shaped electrodes using a Ce$_{1.9}$Gd$_{0.1}$O$_{1.95}$ electrolyte. The activity of the La$_{1-x}$Sr$_x$FeO$_{3-delta}$ based perovskites towards the electrochemical reduction of oxygen was strongly dependent of the strontium content, the activity being highest for the composition La$_{0.85}$Sr$_{0.15}$FeO$_{3-delta}$. The results indicates that Fe(III) is the catalytic active specie towards the electrochemical reduction of oxygen in a solid oxide fuel cell on La$_{1-x}$Sr$_x$FeO$_{3-delta}$ compounds. The results also show that oxide ion vacancies in the perovskite structure are important for the electrochemical reduction of oxygen. However, the effect of ordering of oxide ion vacancies for the strontium rich compounds can not be excluded.

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

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Final report on in-reactor creep-fatigue deformation behaviour of a CuCrZr alloy: COFAT 2

The main objective of the present work was to determine experimentally the mechanical response and resulting microstructural changes in CuCrZr (HT1) alloy exposed concurrently to flux of neutrons and creep-fatigue cyclic loading directly in a fission reactor. Using specially designed test facilities for this purpose, in-reactor creep-fatigue tests have been performed at strain amplitudes of 0.25 and 0.35 % with a holdtime of 10s in the BR-2 reactor at Mol (Belgium). These tests were performed at the ambient temperatures of 326K and 323K. For comparison purposes corresponding out-of-reactor creep-fatigue tests were also carried out. In the following we first describe the details of the creep-fatigue experiments. We then present the main results on the mechanical response of the material in the form of hysteresis loops and the maximum stress amplitude as a function of the number of creep-fatigue cycles during the out-of-reactor and the in-reactor tests carried out at different strain amplitudes. Finally, the dependence of the number of cycles to failure (i.e. creep-fatigue lifetime) on the strain amplitudes is shown. The details of microstructure of the specimens tested out-of-reactor as well as in the reactor were investigated using transmission electron microscopy. The main results on the mechanical response as well as changes in the microstructure are briefly discussed. The main conclusion emerging from the present work is that the lifetime of the in-reactor tested specimens is by a factor of about two longer than in the case of corresponding out-of-reactor tests.

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Fremtidens energiforsyning

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Gas Concentration Impedance in an SOFC Plug Flow Setup

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Department of Chemistry
Contributors: Jensen, S. H., Mogensen, M. B., Jacobsen, T.
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Research output: Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report year: 2008 › Research › peer-review

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.

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Contributors: Hauch, A., Ebbesen, S., Jensen, S. H., Mogensen, M. B.
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Hydrogen and methane oxidation on a gadolinia-doped ceria anode on a YSZ electrolyte

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Contributors: Marina, O., Primdahl, S., Mogensen, M. B.
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Improving the performance of composite LSM cathodes for solid oxide fuel cells

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Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
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Infiltration of SOFC cathodes

General information
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Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Ceramic processing, Electrochemistry
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Ionic and Mixed Conducting Ceramics V

General information
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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
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.
Niobium-doped strontium titanates as SOFC anodes
Sr-vacancy compensated Nb-doped SrTiO(3) with the nominal composition Sr(0.94)Ti(0.9)Nb(0.1)O(3) has been evaluated as part of a solid oxide fuel cell (SOFC) anode material in terms of redox stability, electrical conductivity, as well as electrochemical properties. Sr(0.94)Ti(0.9)Nb(0.1)O(3) has been synthesized with a recently developed modified glycine-nitrate process. The synthesized powders have been calcined and sintered in air or in 9% H(2) / N(2) between 800 - 1400 degrees C. After calcination the samples were single phase Nb-doped strontium titanate with grain sizes of less than 100 nm in diameter on average. The phase purity, defect structure, and microstructure of the materials have been analyzed with SEM, XRD, and TGA. The electrical conductivity of the Nb-doped titanate decreased with increasing temperature and showed a phonon scattering conduction mechanism with sigma > 120 S/cm at 1000 degrees C (in 9% H(2) / N(2)). The electrochemical properties of Sr(0.94)Ti(0.9)Nb(0.1)O(3) and a composite electrode of Sr(0.94)Ti(0.9)Nb(0.1)O(3)/YSZ have been investigated by using a symmetrical cell configuration. The tests indicated that the electrodes were redox stable and showed a potential ability of the Nb-doped titanates to be used as a part of a SOFC anode. However, the catalytic activity of the materials was not sufficient and it needs to be improved if titanate based materials are to be realized as constituents in SOFC anodes.

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Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Blennow Tullmar, P., Kammer Hansen, K., Wallenberg, L. R., Mogensen, M. B.
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On/Off Photoswitching of the Electropolymerizability of Terthiophenes
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Contributors: Areephong, J., Kudernac, T., de Jong, J. J., Carroll, G. T., Pantorott, D., Hjelm, J., Browne, W. R., Feringa, B. L.
Pages: 12850-12851
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Oxygen Nonstoichiometry and Defect Chemistry Modelling of Ce\textsubscript{0.8}Pr\textsubscript{x}Tb\textsubscript{0.2-x}O\textsubscript{2-δ}

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Contributors: Chatzichristodoulou, C., Hendriksen, P. V., Hagen, A., Grivel, J.
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Publication date: 2008
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Performance and Electrochemical Characterisation of Thin Electrolyte SOFCs
The performance and electrochemical behavior of two anode-supported thin electrolyte cells, with different manufacturing parameters, is determined by polarization measurements and electrochemical impedance spectroscopy (EIS). In addition to characterization, a previously suggested equivalent circuit consisting of a series resistance (Rs) and five arcs to describe the polarization resistance of the cell is tested. The aim is to breakdown and assign the losses to each individual cell component around open circuit voltage at selected temperatures. As will be seen, the proposed in-depth electrochemical characterization can provide valuable guidelines for production/performance optimization.

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Performance and Electrochemical Characterisation of Thin Electrolyte SOFCs

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Contributors: Ramos, T., Hjelm, J., Wandel, M., Hagen, A., Mogensen, M. B.
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Performance, degradation and microstructure of LSCF/CGO composite cathodes

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Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Microstructures and Interfaces, Electrochemistry
Contributors: Wandel, M. E., Bowen, J. R., Mogensen, M. B.
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Publisher: European solid oxide fuel cell forum

Photochromism and electrochemistry of a dithienylcyclopentene electroactive polymer

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Recent progress in the development of electrodes and electrolytes for SOFC

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
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Separation of process contributions in impedance spectra by variation of test conditions

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Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Physical Chemistry, Department of Chemistry
Contributors: Jensen, S. H., Jacobsen, T., Mogensen, M. B.
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Source ID: 231638
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2008 › Research

SOFC Ni-electrode Resistance Distribution Investigated by Gas Concentration Impedance in a Plug-Flow Setup

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Physical Chemistry, Department of Chemistry
Contributors: Jensen, S. H., Hendriksen, P. V., Mogensen, M. B., Jacobsen, T.
Pages: 307-315
Publication date: 2008
Peer-reviewed: Yes
SOFC research and development at Risø DTU

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Menon, M., Hjelm, J.
Publication date: 2008
Peer-reviewed: No

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
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Hauch, A., Ebbesen, S., Jensen, S. H., Mogensen, M. B.
Pages: B1184-B1193
Publication date: 2008
Peer-reviewed: Yes

Publication information
Journal: Journal of the Electrochemical Society
Volume: 155
Issue number: 11
ISSN (Print): 0013-4651
Ratings:
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.595 SNIP 1.412
Web of Science (2008): Indexed yes
Original language: English
Electronic versions:
Solid oxide fuel cell research and development at Topsoe Fuel Cell A/S and Risø DTU

General information
Publication status: Published
Contributors: Christiansen, N., Hansen, J., Holm-Larsen, H., Jørgensen, M., Kuhn, L. T., Hendriksen, P. V., Hagen, A., Linderoth, S.
Publication date: 2008

Host publication information
Title of host publication: Proceedings (on CD-ROM)
Publisher: European solid oxide fuel cell forum
Source: orbit
Source ID: 231627
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2008 – Research

Strontium Titanate-based Composite Anodes for Solid Oxide Fuel Cells
Surfactant-assisted infiltration of Gd-doped ceria (CGO) in Nb-doped SrTiO3 (STN) was investigated as a potential fuel electrode for solid oxide fuel cells (SOFC). An electronically conductive backbone structure of STN was first fabricated at high temperatures and then combined with the mixed conducting and electrochemically active nano-sized CGO phase at low temperatures. Symmetrical cell measurements at open circuit voltage (OCV), showed that the electrochemical activity was maintained or even improved compared to Ni/YSZ fuel electrodes. The novel electrode had an electrode polarization resistance of 0.12 Ohm cm² and 0.44 Ohm cm² in humidified H2 at 850 ºC and 650 ºC, respectively. In addition, the ceramic composite electrode was shown to be redox stable. The electrode was actually activated with redox cycles at 650 ºC. The ceramic electrode structure thus presents a potential solution to overcome some of the major limitations of the current Ni-YSZ cermet SOFC anodes.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Blennow Tullmar, P., Kammer Hansen, K., Wallenberg, L., Mogensen, M. B.
Pages: 181-194
Study of Internal and External Leaks in Tests of Anode-Supported SOFCs

A planar anode-supported solid oxide fuel cell (SOFC) has been tested to investigate gas tightness of the electrolyte and the applied seals. Gas leaks reduce the efficiency of the SOFC and it is thus important to determine and minimise them. Probe gases (He and Ar) and a Quadrupole Mass Spectrometer were used to detect both internal (through electrolyte) and external (through seals) gas leaks. The internal gas leak through the electrolyte was quantified under different conditions, as was the external leak from the surroundings to the anode. The internal gas leak did not depend on the pressure difference between the anode and the cathode gas compartment, and can thus be described as diffusion driven. External leaks between the surroundings and the anode, but not the cathode gas compartment was observed. They were influenced by the pressure difference and are thus driven by both concentration and pressure gradients. The measured gas leaks deduced from the probe gas experiments and the total leak calculated from the deviation between the Emf
defined by the gases and the cell OCV (which contains all gas leaks as well as effects of electronic leaks) were compared. Good agreement between the two measures was observed.

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
Contributors: Rasmussen, J. F. B., Hendriksen, P. V., Hagen, A.
Pages: 385-393
Publication date: 2008
Peer-reviewed: Yes

**Publication information**
Journal: Fuel Cells
Volume: 8
Issue number: 6
ISSN (Print): 1615-6846
Ratings:
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.506 SNIP 1.206
Web of Science (2008): Indexed yes
Original language: English
DOIs: 10.1002/fuce.200800019
Source: orbit
Source ID: 235559
Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

**Temperature dependence of the cation distribution in ZnFe2O4 measured with high temperature neutron diffraction**

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Bræstrup, F. R., Hauback, B., Kammer Hansen, K.
Pages: 2364-2369
Publication date: 2008
Peer-reviewed: Yes

**Publication information**
Journal: Journal of Solid State Chemistry
Volume: 181
Issue number: 9
ISSN (Print): 0022-4596
Ratings:
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.988 SNIP 1.203
Web of Science (2008): Indexed yes
Original language: English
DOIs: 10.1016/j.jssc.2008.05.028
Source: orbit
Source ID: 227943
Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

**Testing and improving the redox stability of Ni-based SOFC**

**General information**
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry, Electroceramics
Contributors: Pihlatie, M., Hagen, A., Ramos, T., Barfod, R., Kaiser, A.
Publication date: 2008
The action of nano-particles in SOFC electrodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Ceramic processing
Contributors: Mogensen, M. B., Søgaard, M., Blennow Tullmar, P., Kammer Hansen, K.
Publication date: 2008

Host publication information
Title of host publication: Proceedings (on CD-ROM)
Publisher: European solid oxide fuel cell forum
Source: orbit
Source ID: 231631
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2008 – Research

The Course of O₂ Partial Pressure and Electric Potential Across an Oxide Electrolyte Cell

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Department of Chemistry
Contributors: Mogensen, M. B., Jacobsen, T.
Pages: Abstract 381
Publication date: 2008

Host publication information
Title of host publication: Meeting Abstracts - Electrochemical Society
Publisher: The Electrochemical Society
Electronic versions:
Jacobsen.pdf

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Source: orbit
Source ID: 264286

The Course of Oxygen Partial Pressure and Electric Potentials across an Oxide Electrolyte Cell

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Physical Chemistry, Department of Chemistry
Contributors: Mogensen, M. B., Jacobsen, T.
Pages: 259-273
Publication date: 2008
Peer-reviewed: Yes

Publication information
Journal: ECS Transactions
Volume: 13
Issue number: 26
ISSN (Print): 1938-5862
Transport, Thermal Expansion and Redox Properties of Ce_{0.80}RE_{0.20}O_{2-δ} (RE=Pr, Tb) Solid Solutions

General information
Publication status: Published
Contributors: Chatzichristodoulou, C., Grivel, J., Hagen, A., Hendriksen, P. V.
Pages: Abstract 395
Publication date: 2008

Host publication information
Title of host publication: Meeting Abstracts - Electrochemical Society
Publisher: The Electrochemical Society

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Valence of Pr and Tb in Ce_{0.80}(Pr,Tb)_{0.20}O_{2-δ} solid solutions

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Chatzichristodoulou, C., Hagen, A.
Pages: 895-896
Publication date: 2008

Host publication information
Title of host publication: HASYLAB Annual Report 2007
Volume: Part 1
Publisher: HASYLAB
URLs:

Valency studies in the (Co, Cr, Mn)3O4 spinel system by K-edge XANES

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Östby, J., Hagen, A.
Solid Oxide Electrolyser Cell

Solid oxide fuel cells (SOFCs) produced at Risø National Laboratory were tested as steam electrolyzers under various current densities, operating temperatures and steam partial pressures. At 950 °C and a cell voltage of 1.48V the current density was -3.6A/cm² with approx. 30% H₂ + 70% H₂O in the inlet gas and a H₂O utilization of approx. 40%. The tested SOECs were also used for CO₂ electrolysis. Economy studies of CO and H₂ production show that especially H₂ production can be competitive in areas with cheap electricity. Assuming the above described initial performance and a lifetime of 10 years it is possible to achieve a production price of 0.7 US$/kg H₂ with an electricity price of 1.3 US¢/kWh. The cell voltage was measured as function of time. In test of about two months duration a long-term degradation was observed. At 850 °C, -0.5 A/cm² with 50 vol% H₂, the degradation rate was approx. 20 mV/1000h. It was shown that the degradation happens at Ni/YSZ-electrode. The long-term degradation is probably caused by coarsening of the Ni-particles. After onset of electrolysis operation a transient passivation/reactivation phenomena with duration of several days was observed. It was shown that the phenomenon is attributed to the SiO₂ contamination at the Ni/YSZ-electrode-electrolyte interface. The SiO₂ arises from the albite glass sealing (NaAlSi₃O₈) that surrounds the electrode. Si may enter the Ni/YSZ-electrode via the reaction Si(OH)₄(g) ⇌ SiO₂(l) + H₂O(g). At the active sites of the Ni/YSZ electrode steam is reduced via the reaction H₂O + 2e⁻ → H₂ + O²⁻. This shifts the equilibrium of the first reaction to form SiO₂(l) at the active sites. After a certain time the sealing crystallizes and the SiO₂(l) evaporates from the active sites and the cell reactivates. The passivation is shown to relate to a build up of a diffusion-type impedance arc that converges towards (jω)⁻¹ for the frequency ω converging towards infinity.

A Critical Review of Models of the H₂/H₂O/Ni/SZ Electrode Kinetics

Various models of the H₂/H₂O/Ni/SZ (SZ = stabilized zirconia) electrode kinetics have been presented in the literature in order to explain the reported experimental data. However, there has been a strong tendency of using a limited set of data to "verify" a given model, disregarding other data sets, which do not fit the model. We have inspected some models in the literature, and problems (e.g. no quantitative model has explained the large variation in reported values of apparent activation energy of the electrode kinetics) as well as strengths of the models are discussed. We point out experimental findings that a useful model must be able to explain such differences in sensitivity to poisoning by H₂S due to differences in the detailed composition of the SZ and large change in apparent activation energy by change in cermet preparation. Finally, we will point out some elements, which seem important for any realistic and useful mathematical model of the H₂/H₂O/Ni/SZ electrode.
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.
A-site deficient (La0.6Sr0.4)1-sFe0.8Co0.2O3-delta perovskites as SOFC cathodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Kammer Hansen, K., Hansen, K. V.
Pages: 1379-1384
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Solid State Ionics
Volume: 178
ISSN (Print): 0167-2738
Ratings:
Scopus rating (2007): SJR 1.292 SNIP 1.378
Web of Science (2007): Indexed yes
Original language: English
DOIs:
10.1016/j.ssi.2007.07.012
Source: orbit
Source ID: 215812
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

A study of cathode/electrolyte interface by Spectra Imaging

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Liu, Y.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at Thermo Fisher scientific microanalysis Nordic users meeting, Risø, Denmark.
Source: orbit
Source ID: 216675
Research output: Contribution to conference › Paper – Annual report year: 2007 › Research

Boundary based segmentation of 2D electron microscope images. Ph.D. presentation

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Jørgensen, P. S.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
Source: orbit
Source ID: 216098
Research output: Contribution to conference › Paper – Annual report year: 2007 › Research

Characterisation of the (La1-xSr1-x)0.99Co0.6+xNi0.4-x O3-δ SOFC cathode material
Conductivity and electrochemical characterization of PrFe_{1-x}Ni_{x}O_{3-δ} at high temperature

PrFe_{1-x}Ni_{x}O_{3-δ} compounds were synthesized and characterized by powder XRD, electrical conductivity and electrochemical impedance spectroscopy on point electrodes on a Ce0.9Gd0.1O_{2-δ} (CGO10) electrolyte. As a reference, the electrochemical performance of LaFe_{0.4}AM_{0.6}O_{3-δ} was also measured. The main phase in the PrFe_{1-x}Ni_{x}O_{3-δ} series was perovskite-type structure and belonged to the orthorhombic crystal system. The conductivities are fairly high, e.g. around 220 S cm\(^{-1}\) at 873 K for the \(x = 0.4\) compound. The electrochemical performance of the PrFe_{1-x}Ni_{x}O_{3-δ} series is similar to that of La0.6Sr0.4Fe0.8Co0.2O_{3-δ}, which is a good candidate as a cathode material for SOFCs operating at intermediate temperature. The electrochemical performance of LaFe0.4Ni0.6O_{3-δ} was even higher than that of the PrFe_{1-x}Ni_{x}O_{3-δ} series and the polarization resistance was 0.14 \(\Omega\) cm\(^2\) at 1073 K measured on a point electrode. (c) 2006 Elsevier B.V. All rights reserved.

Conductivity of SrTiO\(_3\) based oxides in the reducing atmosphere at high temperature

The conductivities of several donor-doped SrTiO\(_3\) based oxides, which were prepared in air, were studied in a reducing atmosphere at high temperature. The conductivities of all specimens increased slowly with time at 1000 degrees C in 9% H\(_2\)/N\(_2\), even after 100 h. Nb-doped SrTiO\(_3\) showed relatively fast reduction and high conductivity compared with the other SrTiO\(_3\) based oxides. The conductivity of Nb-doped SrTiO\(_3\) was ca. 50 S cm\(^{-1}\) at 500 degrees C after reduction at 1200 degrees C. After strong reduction, the conductivity of Nb-doped SrTiO\(_3\) was almost independent of the oxygen partial pressure at 500-800 degrees C, while that of La-doped SrTiO\(_3\) dropped immediately on exposure to air. The conduction behavior of Nb-doped SrTiO\(_3\) was explained by reduction of Ti\(^{4+}\) and/or Nb\(^{5+}\) and the relatively slow oxygen diffusibility. (c) 2006 Elsevier B.V. All rights reserved.
Defect structure study of Nb-doped SrTiO3 by Ti K-edge XANES

Detailed characterization of anode-supported SOFCs by impedance spectroscopy
Dimensional behaviour of Ni-YSZ anode supports for SOFC under redox cycling conditions

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Electrochemistry
Contributors: Pihlatie, M., Kaiser, A., Larsen, P. H., Mogensen, M. B.
Pages: 1501-1510
Publication date: 2007

Host publication information
Title of host publication: Proceedings
Volume: Pt. 2
Place of publication: Pennington, NJ
Publisher: The Electrochemical Society
Editors: Eguchi, K., Singhal, S., Yokokawa, H., Mizusaki, J.
ISBN (Print): 978-1-56677-554-0
(E C S Transactions; No. 1, Vol. 2007-07).
DOIs:
10.1149/1.2433311
Source: orbit
Source ID: 216541
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

Durability of solid oxide electrolysis cells for hydrogen production

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Hauch, A., Jensen, S. H., Ebbesen, S., Mogensen, M. B.
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
(Denmark. Forskningscenter Risoe. Risoe-R; No. 1608(EN)).
Keywords: Risø-R-1608, Risø-R-1608(EN)
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Source: orbit
Source ID: 216410
Effect of H2S on performance of Ni-YSZ anodes in solid oxide fuel cells

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Rasmussen, J., Hagen, A.
Publication date: 2007
Peer-reviewed: No
Event: Abstract from Materials science and technology 2007 conference and exhibit (MS&T '07), Detroit (US).
Source: orbit
Source ID: 215661
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2007 › Research

Effect of microstructural inhomogeneity on creep response of Mg-Sn alloys

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Huang, Y., Hort, N., Leil, T., Kainer, K., Liu, Y.
Publication date: 2007
Peer-reviewed: Yes
Publication information
Volume: 345-346
Original language: English
Source: orbit
Source ID: 216471
Research output: Contribution to journal › Conference article – Annual report year: 2007 › Research › peer-review

Effect of transition metal ions on the conductivity and stability of stabilized zirconia

Zirconia compounds stabilised with rare-earth metal oxides like yttria, ytterbia and scandia are known to be good oxide ion conductors suitable as electrolyte material in solid oxide fuel cells. However, stabilised zirconia with high oxide ion conductivity is often only metastable at fuel cell operation temperatures and changes in temperature or oxygen partial pressure together with long-term operation are seen to induce partial destabilisation and even phase changes. In order to avoid these effects co-doping has proven helpful. Based on experimental data available in literature, we discuss the effect of co-doping with smaller transition metal ions such as Ti-, Fe- and Mn-ions. Many of the ionic radii of the transition metal ions are too small compared to the host lattice ionic radius of zirconium. Here we explore the effect of a) the small ionic radii compared to the large ionic radii of the host lattice and b) the preferred six coordination compared to the desired eight-fold coordination of the fluorite structure. Particular interest is paid to the solubility of the transition metal ions and to the conductivity of the resulting material.

Indium is not a transition metal but due to the size of the ionic radius of the metal, the effect of doping with In is also explored.

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Lybye, D., Mogensen, M. B.
Publication date: 2007
Peer-reviewed: Yes
Publication information
Journal: Ceramic Engineering and Science Proceedings
Effects of firing schedule on solubility limits and transport properties of ZrO$_2$–TiO$_2$–Y$_2$O$_3$ fluorites

The low Y/high Zr edge of the cubic defect fluorite solid solution in the system ZrO$_2$–TiO$_2$–Y$_2$O$_3$ in air is reassessed, as it is these compositions which have been suggested to offer the highest levels of mixed conductivity. Vegard's law is obeyed for values of $x$ which lie within the cubic defect fluorite phase in Zr$_{1-x-y}$Y$_y$Ti$_x$O$_{2-\delta}$ for values of $y=0.2$ and 0.25. Measured lattice parameters show good agreement with those calculated from the Kim relation. Deviation from Vegard's law places the limit of the solid solution at $x=0.18$ and 0.20 for values of $y=0.2$ and 0.25, respectively, at 1500 °C. Discrepancies in current literature data can be shown to be due to differences in firing schedule such as slight temperature fluctuations and/or different cooling rates. A high level of care of sintering temperature and cooling profile is essential to form the most promising single-phase materials which contain maximum Ti-contents with low Y-contents. Contraction of the phase limit as a result of poor synthesis control leads to erroneously high values of bulk ionic conductivity while values of electronic conductivity are shown to be less affected.

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, University of Aveiro, University of St Andrews
Contributors: Fagg, D., Frade, J., Mogensen, M. B., Irvine, J.
Pages: 2371-2376
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Journal of Solid State Chemistry
Volume: 180
Issue number: 8
ISSN (Print): 0022-4596
Ratings:
Scopus rating (2007): SJR 1.066 SNIP 1.299
Web of Science (2007): Indexed yes
Original language: English
DOIs: 10.1016/j.jssc.2007.06.016
Source: orbit
Source ID: 255274
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

Effects of trace elements at the Ni/ScYSZ interface in a model solid oxide fuel cell anode.

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Polymers for Energy Technology, Polymer Department
Contributors: Schmidt, M. S., Hansen, K. V., Normann, K., Mogensen, M. B.
Publication date: 2007
Peer-reviewed: No
Event: Abstract from 16th International conference on solid state ionics (SSI-16), Shanghai, China.
URLs:
Source: orbit
Source ID: 215660
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2007 › Research
Electrochemical Impedance Studies of SOFC Cathodes

Mixed ion- and electron-conducting composite electrodes consisting of doped ceria and perovskite have been studied by electrochemical impedance spectroscopy (EIS) at different temperatures and oxygen partial pressures. This paper aims to describe the different contributions to the polarisation impedance of the cathode at intermediate operating temperatures. The perovskite is of the La-Sr-Co-Fe type. The EIS response of symmetrical cells with a thick (similar to 200 μm) gadolinia doped ceria electrolyte was compared with the impedance contribution of the cathode of a full anode supported cell. The full cells had a Ni-YSZ anode and anode support, a thin YSZ electrolyte, and a CGO barrier layer. The symmetric and full cell cathode responses were compared at open-circuit voltage. Humidified hydrogen was used as the fuel in the full cell measurements. Differential analysis of the impedance data was used to identify frequency ranges where changes occur upon degradation and oxygen partial pressure variations.

General information
Publication status: Published
Contributors: Hjelm, J., Søgaard, M., Wandel, M., Mogensen, M. B., Menon, M., Hagen, A.
Pages: 1261-1270
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: ECS Transactions
Volume: 7
Issue number: 1
ISSN (Print): 1938-5862
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Scopus rating (2007): SJR 0.213 SNIP 0.225
Original language: English
Electronic versions:
Hjelm.pdf
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10.1149/1.2729227
URLs:
http://dx.doi.org/10.1149/1.2729227

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Source: orbit
Source ID: 264268
Research output: Contribution to journal › Conference article – Annual report year: 2007 › Research › peer-review

Electrochemical reduction of NO₂ studied by the use of cone-shaped electrodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Kammer Hansen, K.
Pages: 2721-2724
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Electrochemistry Communications
Volume: 9
ISSN (Print): 1388-2481
Ratings:
Scopus rating (2007): SJR 1.991 SNIP 1.509
Web of Science (2007): Indexed yes
Original language: English
DOIs:
Electrochemical removal of NOx. Ph.D. presentation

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Werchmeister, R. M. L.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
Source: orbit
Research output: Contribution to conference > Paper – Annual report year: 2007 > Research

EM investigations of impurities in a fuel cell H2 electrode

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
Contributors: Hauch, A., Jensen, S. H., Kuhn, L. T., Mogensen, M. B.
Publication date: 2007
Peer-reviewed: No
URLs:
Source: orbit
Research output: Contribution to conference > Conference abstract for conference – Annual report year: 2007 > Research

Energy supply technologies. Hydrogen

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for SustainableEnergy
Contributors: Hagen, A., Jensen, J., Jørgensen, B.
Pages: 40-43
Publication date: 2007

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Title of host publication: Risø energy report 6. Future options for energy technologies
Publisher: Risø National Laboratory
Editors: Larsen, H., Sønderberg Petersen, L.
ISBN (Print): 978-87-550-3611-6
(Denmark. Forskningscenter Risoe. Risoe-R; No. 1612(EN)).
Keywords: Risø-R-1612(EN), Risø-R-1612
Electronic versions:
ris_r_1612.pdf
Source: orbit
Research output: Chapter in Book/Report/Conference proceeding > Book chapter – Annual report year: 2007 > Research > peer-review

Gd$_{0.6}$Sr$_{0.4}$Fe$_{0.8}$Co$_{0.2}$O$_{3-\delta}$: A novel type of SOFC cathode

The fabrication and electrochemical activity of a type of solid oxide fuel cell (SOFC) cathode is described in this paper. In search of new cathodes a Gd$_{0.6}$Sr$_{0.4}$Fe$_{0.8}$Co$_{0.2}$O$_{3-\delta}$ compound was synthesized using the glycine-nitrate method. It
turned out that this was a two-phase compound consisting of two perovskite phases, a cubic and an orthorhombic phase, as shown by Rietveld refinements. These two phases were synthesized and a cone-shaped electrode study was undertaken. It was shown that the composite cathode had an electrochemical activity superior to that of the two single-phase perovskites, indicating that the unique microstructure of this type of cathode is essential for achieving high electrochemical activity toward the reduction of oxygen in a SOFC.
Hydrogen and synthetic fuel production from renewable energy sources

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Ceramic processing
Contributors: Jensen, S. H., Larsen, P. H., Mogensen, M. B.
Pages: 3253-3257
Publication date: 2007
Peer-reviewed: Yes

**Publication information**
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Ratings:
Scopus rating (2007): SJR 1.266 SNIP 2.24
Web of Science (2007): Indexed yes
Original language: English
DOIs: 10.1016/j.ijhydene.2007.04.042

Influence of BaO in perovskite electrodes for the electrochemical reduction of NOx
Using the point electrode method, the effect of BaO on electrochemical reduction of NO (x) was investigated using the perovskites La0.85Sr0.15MnO3 (LSM15) and La0.85Sr0.15CoO3 (LSCo15) as electrode materials. The experiments were carried out in the temperature range 400-600 degrees C in 1% NO and 10% O-2, respectively. For the LSM15 electrode the ability to reduce NO compared to O-2 was increased when applying 20 wt% BaO in the electrode while the current density of the electrode was decreased approximately a decade. For the pure LSM15 electrode the highest current density ratio of NO and O-2 was obtained at 400 degrees C while the optimal temperature in term of current density ratios was 500 degrees C for the LSM15 + BaO and LSM15 + BaO + Pt electrodes. The activity of the electrode decreases when applying BaO or BaO + Pt to the electrode except for the LSM15 + BaO + Pt electrode at 500 degrees C where the activity is approximately the same as for the LSM15 electrode. The formation of Ba(NO3)(2) was clearly seen when applying 16.7 wt% BaO and 2 wt% Pt to the electrode. Generally it was observed that at 400 degrees C the activity of the electrodes were low, while at 600 degrees C the kinetics favored oxygen reduction compared to reduction of nitric oxide. The LSCO15 electrode containing BaO reacted to form a K2NiF4-structure and was not tested further.

**General information**
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Electrochemistry, Fuel Cells and Solid State Chemistry Division
Contributors: Simonsen, V. L. E., Johnsen, M., Kammer Hansen, K.
Pages: 131-135
Publication date: 2007
Peer-reviewed: Yes

**Publication information**
Journal: Topics in Catalysis
Volume: 45
Issue number: 1-4
ISSN (Print): 1022-5528
Ratings:
Scopus rating (2007): SJR 1.542 SNIP 1.336
Web of Science (2007): Indexed yes
Original language: English
DOIs:
Inter-diffusion between Co3O4 coatings and the oxide scale on Fe-22Cr

The oxidation behaviour of a commercially available Fe-22Cr alloy coated with a Co3O4 layer by spray-painting or plasma-spraying was investigated at 1173K in air with 1% H2O and compared to the oxidation behaviour of the non-coated alloy. The oxide morphology was examined with X-ray diffraction, electron microscopy, and energy dispersive X-ray spectroscopy. Cr2O3 developed in-between the Co3O4 coating and the alloy, whilst alloying elements of the substrate were incorporated in the coating, regardless of the deposition method. The coatings reduced the growth rate of the Cr2O3 layer as well as the evolution in contact resistance with time between two Fe-22Cr plates sandwiched around a Pt-mesh. SiO2 developed as particles within the alloy during oxidation of the Co3O4 spray-painted samples, whereas SiO2 was identified as an interfacial layer between Cr2O3 and the alloy after oxidation of the Co3O4 plasma-sprayed and the non-coated samples. The difference in morphology is suggested to be an effect of SiO2 nucleation assisted by Kirkendall void formation.

General information
Publication status: Published
Contributors: Hansson, A. N., Linderoth, S., Mogensen, M. B., Somers, M. A. J.
Pages: 193-201
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Journal of Alloys and Compounds
Volume: 433
Issue number: 1
ISSN (Print): 0925-8388
Ratings:
Scopus rating (2007): SJR 0.882 SNIP 1.201
Web of Science (2007): Indexed yes
Original language: English
DOI:
10.1016/j.jallcom.2006.06.086
Source: orbit
Source ID: 198557
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

LSM-YSZ Interface reactions during long-term heat treatment

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Chen, M., Liu, Y., Hendriksen, P. V., Hagen, A.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at 16th International conference on solid state ionics (SSI-16), Shanghai, China.
Source: orbit
Source ID: 215636
Research output: Contribution to conference › Paper – Annual report year: 2007 › Research

Microstructural characterization of Ni-YSZ composites by low-voltage scanning electron microscopy in FE-SEM

General information
Publication status: Published
Contributors: Liu, Y., Thydén, K. T. S., Bilde-Sørensen, J.
Publication date: 2007
Microstructural investigations of Mg-Al alloys containing small amounts of SiC nucleants

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Huang, Y., Hort, N., Anopuo, O., Kainer, K., Vidrich, G., Schiffl, A., Liu, Y.
Pages: 421-426
Publication date: 2007

Host publication information
Title of host publication: Magnesium technology 2007
Place of publication: Warrendale, PA
Publisher: The Minerals, Metals & Materials Society
Editors: Beals, R., Luo, A., Neelameggham, N., Pekguleryuz, M.
ISBN (Print): 978-0-87339-663-9
Source: orbit
Source ID: 216495
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2007
Peer-review

Nanoscale chemical analysis and imaging of solid oxide cells

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Hauch, A.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
Source: orbit
Source ID: 216095
Research output: Contribution to conference – Paper – Annual report year: 2007

New method in resolving process, responses in impedance spectra

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Jensen, S.
Publication date: 2007
Peer-reviewed: No
Source: orbit
Source ID: 215891
Research output: Contribution to conference – Paper – Annual report year: 2007

New method in resolving process responses in impedance spectra. Postdoc presentation

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Jensen, S.
Publication date: 2007
New methods for removal of soot and NOx

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Hansen, K.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
Source: orbit
Source ID: 216096
Research output: Contribution to conference – Paper – Annual report year: 2007 – Research

Niobium-doped strontium titanates as SOFC anodes

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Blennow Tullmar, P., Hansen, K., Wallenberg, L., Mogensen, M. B.
Publication date: 2007
Peer-reviewed: No
Event: Abstract from 32. International Cocoa Beach conference and exposition on advanced ceramics and composites, Cocoa Beach, FL (US).
URLs:
Source: orbit
Source ID: 215895
Research output: Contribution to conference – Conference abstract for conference – Annual report year: 2007 – Research

Ni-YSZ solid oxide fuel cell anode behavior upon redox cycling based on electrical characterization
Nickel (Ni)—yttria-stabilized zirconia (YSZ) cermet is a prevalent material used for solid oxide fuel cells. The cermet degrades upon redox cycling. The degradation is related to microstructural changes, but knowledge of the mechanisms has been limited. Direct current conductivity measurements were performed on cerments and cerments where the Ni component was removed. Measurements were carried out before, during, and after redox cycling the cermet. The cermet conductivity degraded over time due to sintering of the nickel phase. Following oxidizing events, the conductivity of the cerments improved, whereas the conductivity of the YSZ phase decreased. An improved model of the redox degradation mechanism was established based on the measurements.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Klemensø, T., Mogensen, M. B.
Pages: 3582-3588
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Journal of the American Ceramic Society
Volume: 90
Issue number: 11
ISSN (Print): 0002-7820
Ratings:
Scopus rating (2007): SJR 1.255 SNIP 1.444
Optimization of screen printed LSM-YSZ cathodes

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics, Electrochemistry
Contributors: Wandel, M. E., Kaiser, A., Mogensen, M. B.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at Materials science and technology 2007 conference and exhibit (MS&T '07), Detroit (US)
Source: orbit
Source ID: 215624

Oxygen nonstoichiometry and transport properties of strontium substituted lanthanum ferrite

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Electroceramics, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Søgaard, M., Hendriksen, P. V., Mogensen, M. B.
Pages: 1489-1503
Publication date: 2007
Peer-reviewed: Yes
Publication information
Journal: Journal of Solid State Chemistry
Volume: 180
ISSN (Print): 0022-4596
Ratings:
Scopus rating (2007): SJR 1.066 SNIP 1.299
Web of Science (2007): Indexed yes
Original language: English
DOIs:
10.1016/j.jssc.2007.02.012
Source: orbit
Source ID: 216236

Passivation and activation of SOFC nanostructured cathodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electroceramics
Contributors: Wang, W., Bentzen, J. J., Jensen, S. H., Bonanos, N., Hendriksen, P. V., Mogensen, M. B.
Pages: 1243-1250
Publication date: 2007
Host publication information
Title of host publication: Proceedings
Volume: Pt. 1
Place of publication: Pennington, NJ
Publisher: The Electrochemical Society
Editors: Eguchi, K., Singhal, S., Yokokawa, H., Mizusaki, J.
Præsentation af forskningscentre bevilget i efteråret 2006: Strategisk elektrokemisk forskningscenter

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at Strategisk energiforskning. Igangværende forskningsprojekter under Det Strategiske Forskningsråd (DSF), Copenhagen, Denmark.
Source: orbit
Source ID: 216521
Research output: Contribution to conference » Paper – Annual report year: 2007 » Research

Production of synthesis gas in solid oxide electrolysis cells

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Ebbesen, S.
Publication date: 2007
Peer-reviewed: No
Source: orbit
Source ID: 215890
Research output: Contribution to conference » Paper – Annual report year: 2007 » Research

Reaction thermodynamics at the LSM-YSZ interface in SOFCs

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Publication date: 2007
Peer-reviewed: No
Source: orbit
Source ID: 215635
Research output: Contribution to conference » Paper – Annual report year: 2007 » Research

Recent advances with the CAHT-SPM

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Hansen, K. V.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
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.
SOFC status at Risø

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Hagen, A.
Publication date: 2007
Peer-reviewed: No
Event: Paper presented at SERC biannual meeting, Risø, Denmark.
Source: orbit
Source ID: 216099
Research output: Contribution to conference > Paper – Annual report year: 2007 > Research

Solid oxide electrolysis for fuel production

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Ebbesen, S., Hauch, A., Jensen, S., Mogensen, M. B.
Publication date: 2007
Peer-reviewed: No
URLs:
http://www.risoe.dk/rispubl/reports/ris-r-1608_presentations.pdf
Source: orbit
Source ID: 216300
Research output: Contribution to conference > Conference abstract for conference – Annual report year: 2007 > Research

Solid oxide fuel cell anode behavior upon redox cycling

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Klemensø, T., Mogensen, M. B.
Pages: 257-268
Publication date: 2007
Solid oxide fuel cell development at Topsoe Fuel Cell A/S and Risø National Laboratory

General information
Publication status: Published
Contributors: Christiansen, N., Hansen, J., Holm-Larsen, H., Linderoth, S., Larsen, P. H., Hendriksen, P. V., Hagen, A.
Pages: 357-362
Publication date: 2007

Solid Oxide Fuel Cell (SOFC) Development in Denmark
The SOFC technology under development at Risø National Laboratory (RISØ) and Topsoe Fuel Cell A/S (TOFC) is based on an integrated approach ranging from basic materials research on single component level over development of cell and stack manufacturing technology to system studies and modelling. The effort also comprises an extensive cell and stack testing program. Systems design, development and test is pursued by TOFC in collaboration with various partners. The standard cells are thin and robust with dimensions of 12 x 12 cm2 and cell stacks are based on internal manifolding. Production of cells is being up-scaled continuously. The durability of the standard stack design with standard cells has been tested for more than 13000 hours including nine full thermal cycles with an overall voltage degradation rate of about 1% per 1000 hours. Recently, the degradation rate has been significantly reduced by introduction of improved stack component materials. 75-cell stacks in the 1+ kW power range have been tested successfully. Stacks have been delivered in a pre-reduced state to partners and tested successfully in test systems with natural gas as fuel. The consortium of TOFC and RISØ has an extended program to develop the SOFC technology all the way to a marketable product. Stack and system modelling including cost optimisation analysis is used to develop multi kW stack modules for operation in the temperature range 700-850oC. To ensure the emergence of cost-competitive solutions, a special effort is focused on larger anode-supported cells as well as a new generation of SOFCs based on porous metal supports and new electrode and electrolyte materials. The SOFC program comprises development of next generation of cells and multi stack modules for operation at lower temperature with increased durability and mechanical robustness in order to ensure long-term competitiveness.

General information
Publication status: Published
Contributors: Linderoth, S., Larsen, P. H., Mogensen, M. B., Hendriksen, P. V., Christiansen, N., Holm-Larsen, H.
Pages: 1309-1314
Publication date: 2007
Peer-reviewed: Yes
Spinels as cathodes for the electrochemical reduction of O₂ and NO

Spinels were synthesised and investigated as electro-catalyst for the electrochemical reduction of oxygen and nitric oxide using cyclic voltammetry and cone shaped electrodes. The following four spinels were investigated; CoFe₂O₄, NiFe₂O₄, CuFe₂O₄ and Co₃O₄. The composition CuFe₂O₄ revealed the largest difference in activity between reduction of oxygen and the reduction of nitric oxide, the activity being highest for the reduction of nitric oxide. The material is probably not stable when polarised cathodically. However it seems that the electrode material can be regenerated upon oxidation. 

NiFe₂O₄ is also more active for the reduction of nitric oxide than for the reduction of oxygen, whereas the cobalt containing spinels have a higher activity for the reduction of oxygen than for the reduction of nitric oxide.

Spinel-type electrode materials for purification of exhaust gasses from diesel fired engines

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Electrochemistry, Fuel Cells and Solid State Chemistry Division
Contributors: Simonsen, V. L. E., Find, D., Lilliedal, M., Petersen, R., Kammer Hansen, K.
Pages: 143-148
Publication date: 2007
Peer-reviewed: Yes

Synthesis and characterization of dinuclear ruthenium(II) complexes based on 4,4'-bipyridyl type gridging ligands

General information
Synthesis of Nb-doped SrTiO₃ by a modified glycine-nitrate process

The objective of the present investigation was to develop a technique to synthesize submicronic particles of Nb-doped strontium titanate with a homogeneous composition. This was achieved by a modified glycine-nitrate process, using Ti-lactate, Nb-oxalate, and Sr(NO₃)₂ as starting materials. A combination of both citric acid and glycine was needed in order to integrate the useful features of both complexation and combustion natures of citric acid and glycine, respectively. The amount of citric acid, glycine, and nitrates in the starting solution, as well as the source for extra nitrates, and the uniformity of heating during the thermal dehydration step were found to have significant influence on the final phase purity of the material. Calcination at 1100 degrees C in 7% H₂ in N₂ produced single phase Nb-doped strontium titanate with grain sizes of about 100 nm in diameter on average. (c) 2007 Elsevier Ltd. All rights reserved.
XANES measurements on nickel- and cobalt-valency in strontium doped lanthanum perovskites

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Hjalmarsson, P., Hagen, A.
Number of pages: 2
Publication date: 2007

Break down of losses in thin electrolyte SOFCs
The contributions of the individual components of the cell (anode, cathode, and electrolyte) to the cell resistance were determined experimentally, directly from impedance spectra obtained from a full cell. It was an anode supported thin electrolyte cell, consisting of a YSZ electrolyte, a Ni/YSZ cermet anode, and a LSM composite cathode. Additional, qualitative information was obtained using symmetric cells with LSM composite electrodes. The investigations were carried out in the temperature interval from 700 to 850 degrees C. The electrolyte and anode activation energies obtained were 0.9 and 1.1 eV, respectively, which is in relatively good agreement with literature values. The anode resistance was 0.24 Omega cm(2) and the cathode resistance was 0.58 Omega cm(2) at 700 degrees C, corresponding to 23% and 56% of the total resistance, respectively.

General information
Publication status: Published
Contributors: Barfod, R., Hagen, A., Ramousse, S., Hendriksen, P., Mogensen, M. B.
Pages: 141-145
Publication date: Apr 2006
Peer-reviewed: Yes

Publication information
Journal: Fuel Cells
Volume: 6
Issue number: 2
ISSN (Print): 1615-6846
Ratings:
Assessment of doped ceria as electrolyte

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Ceramic processing, Fuel Cells and Solid State Chemistry Division, Electrochemistry
Contributors: Dalslet, B. T., Blennow Tullmar, P., Hendriksen, P., Bonanos, N., Lybye, D., Mogensen, M. B.
Pages: 547-561
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Journal of Solid State Electrochemistry
Volume: 10
Issue number: 8
ISSN (Print): 1432-8488
Ratings:
Scopus rating (2006): SJR 0.784 SNIP 0.985
Web of Science (2006): Indexed yes
Original language: English
DOI:
10.1007/s10008-006-0135-x
URLs:

Bibliographical note
This article may be downloaded for personal use only. Any other use requires prior permission of the author and the publisher
Source: orbit
Source ID: 309354
Research output: Contribution to journal › Journal article – Annual report year: 2006 › Research › peer-review

Effects of Sr/Ti-ratio in SrTiO$_3$-based SOFC anodes investigated by the use of cone-shaped electrodes

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Blennow Tullmar, P., Kammer Hansen, K., Wallenberg, L., Mogensen, M. B.
Pages: 1651-1661
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Electrochimica Acta
Volume: 52
ISSN (Print): 0013-4686
Ratings:
Scopus rating (2006): SJR 1.531 SNIP 1.725
Web of Science (2006): Indexed yes
Original language: English
DOI:
10.1016/j.electacta.2006.03.096
Modelling of the Polarization Resistance from Surface Exchange and Diffusion Coefficient Data

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Department of Chemistry, Electrochemistry
Contributors: Søgaard, M., Hendriksen, P. V., Jacobsen, T., Mogensen, M. B.
Pages: 1-17
Publication date: 2006

Host publication information
Title of host publication: 7'th European SOFC Forum
Volume: file B064
Source: orbit
Source ID: 191119
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2006

Ni-YSZ solid oxide fuel cell anode behavior upon redox cycling based on electrical characterization

Ni-YSZ cerments are a prevalent material used for solid oxide fuel cells. However, the cermet degrades upon redox cycling. The degradation is related to microstructural changes, but knowledge of the mechanisms has been limited. DC conductivity measurements were performed on cerments and cerments, where the Ni component was removed, before, during and after redox cycling the cermet. The cermet conductivity degraded over time due to sintering of the nickel phase.

Following oxidizing events, the conductivity of the cerments improved, whereas the conductivity of the YSZ phase decreased. A model of the redox degradation mechanism was established based on the measurements.

General information
Publication status: Published
Organisations: Ceramic processing, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Klemensø, T., Mogensen, M. B.
Number of pages: 23
Publication date: 2006

Host publication information
Title of host publication: Proceedings of Materials Science and Technology 2006 Meeting
Electronic versions: MST_conf_060630.pdf
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2006

Oxygen nonstoichiometry and transport properties of strontium substituted lanthanum cobaltite

Oxygen nonstoichiometry, structure and transport properties of the two compositions (La0.6Sr0.4)(0.99)CoO3-delta (LSC40) and La0.85Sr0.15CoO3-delta (LSC15) were measured. It was found that the oxygen nonstoichiometry as a function of the temperature and oxygen partial pressure could be described using the itinerant electron model. The electrical conductivity, sigma, of the materials is high (sigma > 500 S cm(-1)) in the measured temperature range (650 - 1000 degrees C) and oxygen partial pressure range (0.209-10(-4) atm). At 900 degrees C the electrical conductivity is 1365 and 1491 S cm(-1) in air for LSC40 and LSC15, respectively. A linear correlation between the electrical conductivity and the oxygen vacancy concentration was found for both samples. The mobility of the electron-holes was inversely proportional with the absolute temperature indicating a metallic type conductivity for LSC40. Using electrical conductivity relaxation the chemical diffusion coefficient of oxygen was determined. It was found that accurate values of the chemical diffusion coefficient could only be obtained using a sample with a porous surface coating. The porous surface coating increased the surface exchange reaction thereby unmasking the chemical diffusion coefficient. The ionic conductivity deduced from electrical conductivity relaxation was determined to be 0.45 S cm(-1) and 0.01 S cm(-1) at 1000 and 650 degrees C, respectively. The activation energy for the ionic conductivity at a constant vacancy concentration (delta = 0.125) was found to be 0.90 eV. (c) 2006 Elsevier B.V. All rights reserved.

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Electrochemistry
Performance and durability of solid oxide electrolysis cells
Solid oxide fuel cells produced at Riso National Laboratory have been tested as electrolysis cells by applying an external
tension. 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 Omega 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
Publication status: Published
Organisations: Department of Chemistry, Ceramic processing, Fuel Cells and Solid State Chemistry Division, Rise National Laboratory for Sustainable Energy, Electrochemistry
Contributors: Hauch, A., Jensen, S. H., Ramousse, S., Mogensen, M. B.
Pages: A1741-A1747
Publication date: 2006
Peer-reviewed: Yes

Bibliographical note
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work may not be reproduced, resold, distributed, or modified without the express permission of The Electrochemical Society (ECS).
Source: orbit
Source ID: 195532
Research output: Contribution to journal › Journal article – Annual report year: 2006 › Research › peer-review
Properties and Performance of SOFCs Produced on a Pre-Pilot Plant Scale

In the present paper, anode supported solid oxide fuel cells (SOFCs), produced on a pre-pilot plant scale in ten batches of ~100 cells, are characterised with respect to performance. The main purpose was to evaluate the reproducibility of the scaled-up process. Based on 20 tests, the average area specific cell resistance at 850 °C was found to be 0.24 Ω cm² with a standard deviation of 0.05 Ω cm². The variation in performance between the cells can be largely attributed to variations in the cathode performance. Experimental evidence will be presented on full 4 × 4 cm² cells, symmetric cells with two cathodes on a YSZ strip, and a special cell with a divided cathode.

General information
Publication status: Published
Contributors: Hagen, A., Menon, M., Barfod, R., Hendriksen, P. V., Ramousse, S., Larsen, P. H.
Pages: 146-150
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Fuel Cells
Volume: 6
Issue number: 2
ISSN (Print): 1615-6846
Ratings:
Scopus rating (2006): SJR 1.186 SNIP 1.206
Web of Science (2006): Indexed yes
Original language: English
Keywords: Cathode, Impedance, Reproducibility of Production, SOFC
DOIs:
10.1002/fuce.200500108
Source: orbit
Source ID: 309748
Research output: Contribution to journal › Conference article – Annual report year: 2006 › Research › peer-review

A study of Pr0.7Sr0.3Fe1-xNiₓO3-δ as a cathode material for SOFCs with intermediate operating temperature

Pr0.7Sr0.3Fe1-xNxO3-δ (x=0.2-0.5) compounds were synthesized and characterized by powder X-ray diffraction (XRD), thermal expansion coefficient (TEC) measurements, electrical conductivity and electrochemical impedance spectroscopy on cone-shaped electrodes on a Ce0.9Gd0.1O1.95 (CGO10) electrolyte. The main phase of the powders belongs to the orthorhombic crystal system. The conductivities are fairly high, e.g., around 450 scm⁻¹ at 600 °C; for the x=0.3 compound. The TEC of the compounds is close to the values of ceria-based electrolytes. The electrochemical La0.6Sr0.4Fe0.8Co0.2O3-δ was considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry. The electrochemical analysis showed hysteresis in the temperature dependence of the conductivity, TEC and area-specific polarization resistance Rpol. It is considered that the hysteresis was caused by relatively slow adjustment of the oxygen stoichiometry.

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Electrochemistry, Fuel Cells and Solid State Chemistry Division
Contributors: Hashimoto, S., Kammer Hansen, K., Larsen, P., Poulsen, F., Mogensen, M. B.
Pages: 1013-1020
Publication date: 2005
Peer-reviewed: Yes

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Web of Science (2005): Indexed yes
Original language: English
DOIs:
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High Purity H₂/H₂O/Nickel/Stabilized Zirconia Electrodes at 500°C

General information
Publication status: Published
Organisations: Electroceramics, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Microstructures and Interfaces, Solar Energy Programme, Electrochemistry
Contributors: Høgh, J. V. T., Hansen, K. V., Chorkendorff, I., Jacobsen, T., Normann, K., Mogensen, M. B.
Pages: 159-168
Publication date: 2005

Host publication information
Title of host publication: Ceramic Engineering and Science Proceedings : Proceedings of the 29th Int. Conf. on Ceramics and Composite - Advances in Solid Oxide Fuel Cells
Volume: 26 (4)
Publisher: American Ceramic Society
Source: orbit
Source ID: 183100

Effects of A/B-ratio in strontium doped lanthanum cobaltite
EFFECTS OF A/B-RATIO IN STRONTIUM DOPED LANTHANUM COBALTITE Martin Søgaard a;b, Peter V. Hendriksen a, Dorthe Lybye a, Mogens Mogensen a and Torben Jacobsen b aRisø National Laboratory, Materials Research Department, Frederiksbergvej 399, DK-4000 Roskilde, Denmark bTechnical University of Denmark, Department of Chemistry, DK-2800 Kgs. Lyngby, Denmark ABSTRACT The electrical conductivity of (La0.85Sr0.15)sCoO3-δ, s = 0.98; s = 1.00; s = 1.02 has been measured. The electrical conductivity of the composition s = 0.98 was significantly higher than those of the other two materials at temperatures below 400°C. The chemical diffusion coefficient, DChem, and the apparent surface exchange coefficient, kEx, were measured using electrical conductivity relaxation. The compositions s = 1.02 and s = 0.98 had within the uncertainty the same surface exchange coefficient. kEx was approximately 3 times larger for the composition s = 0.98. It is speculated that the Co-rich material has a surface layer richer in cobalt, which improves the electrochemical activity. DChem, was the same for the compositions s = 0.98 and s = 1.00, whereas it was significantly lower for the s = 1.02 material by approximately 25%. The activation energy for the vacancy diffusion coefficient, DV, was calculated to 75.2 kJ mol⁻¹ for the s = 1.02 composition. Oxygen permeation measurements were carried out on the s = 1.02 composition using an oxygen-pump. The results were in excellent agreement with fluxes calculated from the measured DChem and kEx values using the Wagner equation combined with surface exchange reactions.

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Electrochemistry, Fuel Cells and Solid State Chemistry Division, Department of Chemistry, Technical University of Denmark, Risø National Laboratory
Contributors: Søgaard, M., Hendriksen, P. V., Lybye, D., Mogensen, M. B., Jacobsen, T.
Publication date: 2004
Peer-reviewed: No
Event: Abstract from 206th Meeting of the Electrochemical Society , Honolulu, HI, United States.
Source: orbit
Source ID: 154254
Research output: Contribution to conference – Conference abstract for conference – Annual report year: 2004 – Research

An impedance study of hydrogen oxidation on a gadolinia-doped ceria anode

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Marina, O., Primdahl, S., Mogensen, M. B.
Pages: 171-172
Publication date: 1999

Host publication information
Title of host publication: Extended abstracts
Behaviour of fission gas in the rim region of high burn-up UO₂ fuel pellets with particular reference to results from an XRF investigation

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B., Pearce, J., Walker, C.
Pages: 99-112
Publication date: 1999
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Publication information
Journal: Journal of Nuclear Materials
Volume: 264
ISSN (Print): 0022-3115
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Original language: English
Source: orbit
Source ID: 300622
Research output: Contribution to journal › Journal article – Annual report year: 1999 › Research › peer-review

Brændselsceller

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Publication date: 1999
Peer-reviewed: No
Event: Abstract from Tendenser i moderne kemi. H.C. Ørstedinstituttet, København (DK), 29 Sep.
Source: orbit
Source ID: 299668
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 1999 › Research

Morphological changes at the interface of the nickel-yttria stabilized zirconia point electrode
The H₂-H₂O, Ni/YSZ point electrode has been investigated using long-term potential step measurements and impedance spectroscopy at 1273 K. Morphological and structural changes at the electrode interface were evaluated by electron microscopy, energy dispersive X-ray analysis, and Raman spectroscopy ex situ. The anodic current was found to induce a self-catalytic effect on the electrode, and the anodic "steady state" current increased to more than twice the initial value with a time constant of about 40 h. In contrast, cathodic polarization reduced the performance of the electrode and the cathodic current decreased significantly with a time constant of about 20 h. Redistribution of material in the reaction zone is suggested to control most of the changes in electrode activity. At anodic overpotentials it was observed that Ni was transported to the electrolyte surface, forming a "necklace" of Ni particles around the electrode/electrolyte contact. This is believed to increase the three-phase boundary (TPB) length and account for the higher activity of the electrode. At cathodic overpotentials the transfer of Ni to the YSZ was found to be restricted, and it is proposed that agglomeration of dispersed metal particles reduced the TPB length, and accordingly the cathodic current. In addition to the morphological modifications, the catalytic properties of the surfaces were significantly altered as the electrode was polarized. Transformation from cubic to tetragonal YSZ, due to segregation of the material, was observed on the surface of the electrolyte when the sample was kept at working conditions for long periods of time (135 days). The passage of current was not found to generate any permanent phase transformation in the YSZ.

General information
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division, Electrochemistry, Department of Chemistry, Norwegian University of Science and Technology
A study of the $\text{O}_2$, $\text{Pt}/\text{O}_2^2-$, $\text{Zr}_{0.82}\text{Y}_{0.82}\text{O}_{1.91}$ electrode

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Shkerin, S., Mogensen, M. B.
Pages: 1122-1123
Publication date: 1996

Host publication information
Title of host publication: 189th Society meeting. Spring meeting
Place of publication: Pennington, NJ
Publisher: The Electrochemical Society
(Meeting Abstracts Vol. 96-1).
Source: orbit
Source ID: 295667
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1996 – Research

Kinetic and geometric aspects of solid oxide fuel cell electrodes
The paper gives an overview of the main factors controlling the performance of the solid oxide fuel cell (SOFC) electrodes, emphasizing the most widely chosen anodes and cathodes, Ni-YSZ and LSM-YSZ. They are often applied as composites (mixtures) of the electron conducting electrode material and the ion conducting electrolyte. Some reasons for this choice are: 1) to increase the three-phase-boundary (TPB) length (key reactants must pass the TPB) and 2) to assure good adherence of the electrodes to the electrolyte. In the case of Ni-YSZ cermet anode it is also clear that the electrochemical performance is very much dependent on how it was made (structure and composition). Impedance results show that up to three arcs are present which means that at least three processes may contribute to the polarization resistance. Comparisons with anode microstructure micrographs show that the high frequency arc is much more dependent on the structure than the low frequency arcs. In the case of LSM-YSZ composite it has been demonstrated that both the ratio of LSM to YSZ and the conductivity of the YSZ is of major importance. The length and the nature of the three-phase-boundary between LSM, YSZ and air influence the size of the polarization resistance greatly and may also change the rate limiting step for oxygen reduction as evidenced by the change in dependence on oxygen partial pressure and in the apparent activation energy. $\text{O}_{16}/\text{O}_{19}$ isotope exchange measurements have shown that oxygen surface exchange takes place with significant rates on both electrodes and electrolyte types of materials. Results from pointed electrodes indicate that the electrochemical reaction occurs on both the solid electrolyte and the electrode materials but only in a narrow zone (few micrometers) along the three-phase-boundary.

General information
Physical Properties of Mixed Conductor Solid Oxide Fuel Cell Anodes of Doped CeO$_2$

Samples of CeO$_2$ doped with oxides such as CaO and Gd$_2$O$_3$ were prepared. Their conductivities and expansions on reduction were measured at 1000°C, and the thermal expansion coefficients in the range 50 to 1000°C were determined. The ionic and electronic conductivity were derived from curves of total conductivity vs. oxygen partial pressure. For both types of conductivity a dependence on dopant valency was observed. The electronic conductivity was independent of dopant radius in contrast to the ionic which was highly dependent. These measured physical properties are compared with the ideal requirements for solid oxide fuel cell anodes. Not all requirements are fulfilled. Measures to compensate for this are discussed.

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Haldor Topsoe AS
Contributors: Mogensen, M. B., Lindegaard, T., Hansen, U. R., Mogensen, G.
Pages: 2122-2128
Publication date: 1994
Peer-reviewed: Yes

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Journal: Journal of The Electrochemical Society
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Source: orbit
Source ID: 264168
Research output: Contribution to journal › Journal article – Annual report year: 1994 › Research › peer-review

Determination of Fission Products in Irradiated Fuel by X-Ray Fluorescence

X-ray fluorescence is a well established analytical tool for measuring elemental composition of fairly large (~ 5cm$^2$) “cold” samples. A version of this technique has been developed for analysis of radial distribution of fission products Xe, Cs and Ba in irradiated UO$_2$ fuel samples. About 0.1 mm thin slices of fuel pellets (full cross sections) are irradiated by 50 keV X-rays. The intensity of the Xe (Cs, Ba) Ko fluorescence radiation generated is measured by means of a Ge detector fitted with a collimator. The slit is 0.5 mm wide in the scanning direction and 2 mm long. The measured Xe Ko x-ray intensities are converted to absolute concentrations by comparing to the intensity from a Xe gas standard. In the case of Cs and Ba
solid standards may be used. The X-ray fluorescence analysis is compared to other techniques used to obtain radial fission product profiles, it is shown how a combination of X-ray fluorescence and electron probe micro analysis is able to reveal the amount of Xe in the grain boundary porosities.

**General information**
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Contributors: Mogensen, M. B., Als-Nielsen, J. A., Andersen, N. H.
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Publication date: 1986

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Research output: Book/Report › Report – Annual report year: 1986 › Research

**Fission Product Behaviour in High-Burn-up Water Reactor Fuel Subjected to Slow Power Increases**

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Knudsen, P., Bagger, C., Misfeldt, I., Mogensen, M. B.
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Publication date: 1986
Peer-reviewed: Yes

**Publication information**
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Volume: 72
ISSN (Print): 0029-5450
Original language: English
Source: orbit
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Research output: Contribution to journal › Journal article – Annual report year: 1986 › Research › peer-review

**Frequency Response Analysis: A Tool in the Study of Metal Degradation**

**General information**
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Pages: 255-261
Publication date: 1986

**Host publication information**
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Place of publication: Stockholm
Publisher: Swedish Corrosion Institute
Source: orbit
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Risøs metoder til studier af faststofelektrolytter

General information
Publication status: Published
Organisations: Nano-Microstructures in Materials, Materials Research Division, Risø National Laboratory for Sustainable Energy, Electrochemistry, Fuel Cells and Solid State Chemistry Division, Microstructures and Interfaces
Contributors: Andersen, N. H., Bentzen, J. J., Mogensen, M. B., Poulsen, F. W., Sørensen, O. T.
Pages: 16-17
Publication date: 1986

Host publication information
Title of host publication: Generel og Anvendt Elektrokemi i Danmark. Symposium, DTH, Lyngby, 9 april 1986
Publisher: Dansk Elektrokemisk Forening, Selskabet for Analytisk Kemi
Source: orbit
Source ID: 279018
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1986 › Research › peer-review

Tynde fastelektrolytlag på lithiumelektroder

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Microstructures and Interfaces
Contributors: Mogensen, M. B., Poulsen, F. W.
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Publication date: 1986

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Place of publication: Lyngby, Denmark
Publisher: Dansk Elektrokemisk Forening, Selskabet for Analytisk Kemi
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Udvikling af iltsensorer på Risø

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Bentzen, J. J., Sørensen, O. T.
Pages: 35-36
Publication date: 1986

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Publisher: Dansk Elektrokemisk Forening, Selskabet for Analytisk Kemi
Source: orbit
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1986 › Research › peer-review

Avancerede keramiske materialer

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Bentzen, J. J.
Pages: 181-185
Properties of LiCl Solid Electrolyte Layers formed on Electrodes in LiAlCl4/ SOC12 Liquid Cathodes

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Pages: 233-241
Publication date: 1985

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Place of publication: Risø
Publisher: Risø National Laboratory
Editor: Poulsen, F. W.
Source: orbit
Source ID: 279019
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1985 – Research

The a.c. response of lithium, stainless steel, and porous carbon electrodes in thionyl chloride solutions
Impedance measurements on Li electrodes in SOCl2 electrolytes indicate that the structure of the passivating surface layer formed in 1.8M LiAlCl4 differs from that formed in 1.8M AlCl3, 1.2M LiCl, 0.6M SO2. Also, porous carbon electrodes are found to behave differently in these two electrolytes. Unpolarised stainless steel electrodes show a 67° constant phase angle impedance over a wide frequency range whereas polarised to 0 mV vs. Li the impedance diagram is very similar to that of Li. Finally, it is found that passivation may develop differently for Li pressed onto stainless steel from that of Li pressed onto glass.

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Contributors: Mogensen, M. B.
Pages: 123-127
Publication date: 1985
Peer-reviewed: Yes

Variations in Lithium Electrode Passivation Rate with SOCl2 Catholyte Composition and Temperature

General information
Publication status: Published
Organisations: Electrochemistry, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy
Determination of fission gas yields from isotope ratios
This paper describes a method of calculating the actual fission yield of Kr and Xe in nuclear fuel including the effect of neutron capture reactions and decay. The bases for this calculation are the cumulative yields (ref. 1) of Kr and Xe isotopes (or pairs of isotopes) which are unaffected by neutron capture reactions, and measured Kr and Xe isotope ratios. Also the burnup contribution from the different fissile heavy isotopes must be known in order to get accurate fission gas yields.

Local Fission Gas Release from High Burnup Water Reactor Fuel under Transient Conditions

Host publication information
Place of publication: Vienna
Publisher: International Atomic Energy Agency (IWGFTP; No. 16).
Keywords: IWGFTP-16
Source: orbit
Source ID: 279905
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1983 – Research
Determination of Retained Gas in Irradiated Fuel Samples

Full cross section samples from water reactor fuel pins are oxidized in molten NaNO₃ containing about 10% NaOH and 5% Na₂O₂. During this oxidation the fission gases Kr and Xe are released. The gas volume is measured, and the gas is analysed by mass spectrometry.

The generated amount of gas in the samples analysed is calculated from measured burn-up, from measured Xe and Kr isotope ratios and from fission yields of stable Xe and Kr isotopes with low neutron capture cross sections. From the fission gas generated and measured amount of gas retained, the gas retention and release percentage can be found.

Examples of results are reported. Retained gas plus released gas (measured by puncturing) and the calculated gas generation agreed within 6 percent.
Keywords: Risø-M-2352, Fission yield, Fission products, Fission product release, Fuel pins, Isotope ratio, Krypton, Krypton isotopes, Mass spectroscopy, Measuring methods, Molten salts, Oxidation, Post-irradiation examination, Radiation chemistry, Spent fuels, Uranium dioxide, Xenon, Xenon isotopes

Electronic versions:
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