Conference Agenda

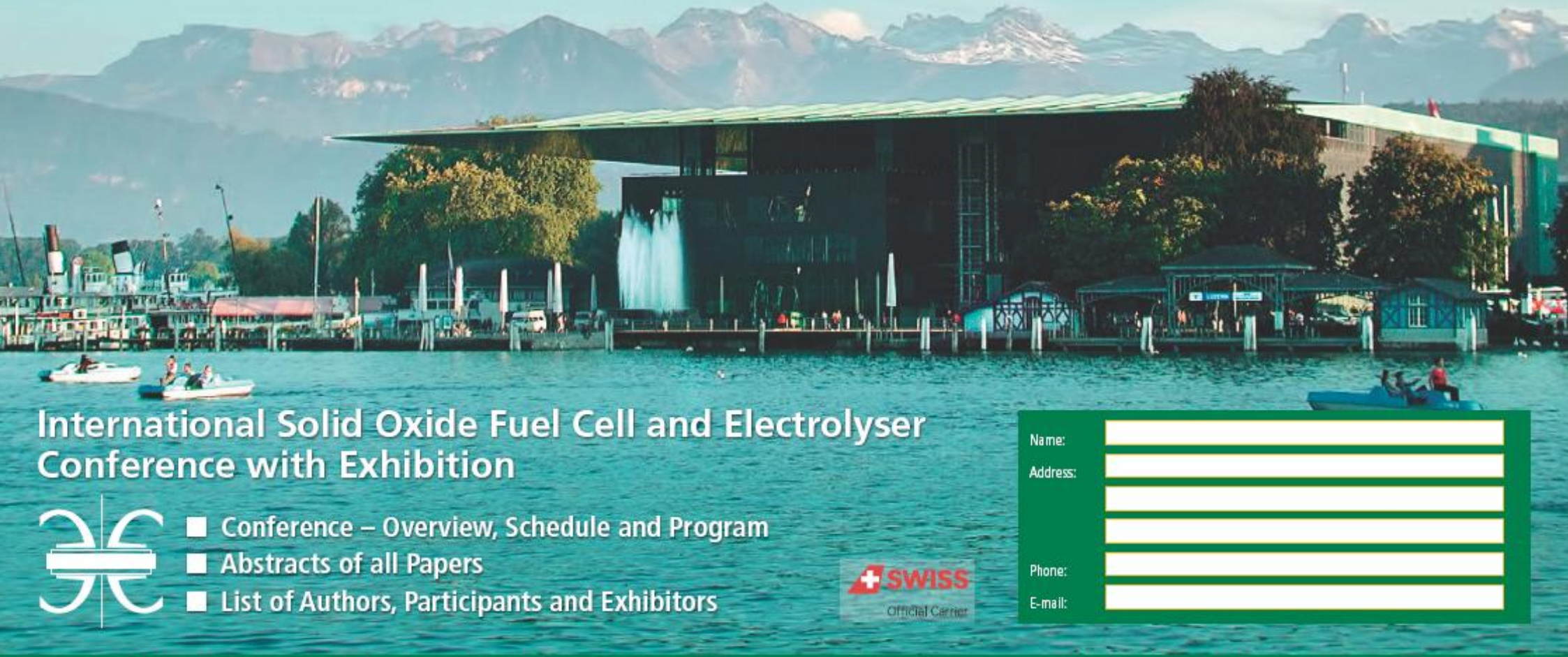
16th conference series of the European Fuel Cell Forum in Lucerne

10th EUROPEAN SOFC FORUM 2012

26 – 29 June 2012, Kultur- und Kongresszentrum Luzern – KKL Lucerne / Switzerland

Chairwoman:

Dr. Florence Lefebvre-Joud CEA-LITEN, Grenoble / France



International Solid Oxide Fuel Cell and Electrolyser Conference with Exhibition

- Conference – Overview, Schedule and Program
- Abstracts of all Papers
- List of Authors, Participants and Exhibitors

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International conference on SOLID OXIDE FUEL CELL and ELECTROLYSER

10th EUROPEAN SOFC FORUM 2012

26 - 29 June 2012

Kultur- und Kongresszentrum Luzern (KKL) Lucerne / Switzerland

Chairwoman: Dr. Florence Lefebvre-Joud

CEA-LITEN, Grenoble/France

Tutorial

by Dr. Günther G. Scherer PSI Villigen, Switzerland
Dr. Jan Van Herle EPF Lausanne, Switzerland

Exhibition

Event organized by European Fuel Cell Forum
Olivier Bucheli & Michael Spirig
Obgardihalde 2, 6043 Luzern-Adligenswil, Switzerland
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10th EUROPEAN SOFC FORUM 2012

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The event is endorsed by:

ALPHEA Rue Jacques Callot FR-57600 Forbach / France	**International Hydrogen Energy Association** P.O. Box 248294 Coral Gables, FL 33124 / USA	**VDI Verein Deutscher Ingenieure** Graf-Reck-Strasse 84 DE-40239 Düsseldorf / Germany
EUROSOLAR e. V. Kaiser-Wilhelm-Strasse 11 DE-53113 Bonn-Bad Godesberg / Germany	**SIA (Berufsgruppe Technik und Industrie)** Selnaustr. 16 CH-8039 Zürich / Switzerland	**Wiley – VCH Publishers** Boschstr. 12 DE-69469 Weinheim / Germany
Euresearch Effingerstr. 19 3001 Bern /Switzerland	**Swiss Academy of Engineering Sciences** Seidengasse 16 CH-8001 Zürich / Switzerland	
FUEL CELLS 2000 1625 K Street NW, Suite 725 Washington, DC 20006 / USA	**Swiss Gas and Water Industry Association** Eschengasse 10 CH-8603 Schwerzenbach / Switzerland	

Welcome by the Organisers

Olivier Bucheli & Michael Spirig

European Fuel Cell Forum
Obgardihalde 2
6043 LUZERN / Switzerland

Welcome to the 10th EUROPEAN SOFC & SOE FORUM 2012. As from the year 2000, this 16th event of a successful series of conferences in Fuel Cell and Hydrogen Technologies takes place in the beautiful and impressive KKL, the Culture and Congress Center of Lucerne, Switzerland. Competent staff, smooth technical services and excellent food allow the participants to focus on science, technology and networking in a creative and productive work atmosphere.

One more time, this event gives us as organiser the challenge to adapt to the evolving needs of the scientific and technical community around high temperature electroceramic technologies. As a natural evolution, for the first time, Solid Oxide Electrolysers are an official part of the program. Besides some minor adaptation, we want to keep one thing constant: The focus on facts and physics. This is granted by the autonomy of the organisation that does not depend on public or private financial sponsors but is fully based on the participants and exhibitors. Your participation has made possible this event, please take those following days as your personal reward!

Since the sad events of March 2011, society has increasingly become aware about the importance of energy. Along with renewables, reduced dependency on fossil and nuclear, efficiency and storage have become part of the daily vocabulary of politicians. Fuel cells and Hydrogen have an important contribution in answering this global challenge. This conference will present the status of the technology, what progress has been achieved, what it can do today, and where the remaining challenges lie.

In this respect, we would like to thank the conference chair Dr. Florence Lefebvre-Joud from CEA Grenoble, France, the CEA team, the Scientific Organising Committee and the Scientific Advisory Committee. Based on closed to 300 (!) submitted scientific contributions, they have composed a sound scientific program picturing the recent progress in high temperature electroceramics from more than 35 countries and 6 continents – we look forward to seeing this exciting program of the EUROPEAN SOFC & SOE FORUM 2012. We also hope that the charming and inspirational atmosphere of Lucerne allows many strong experts to initiate or confirm partnerships that result in true products and solutions for society, and will allow adding some more pieces in the emerging picture of our future energy system.

Our sincere thanks also go to all the presenters, the session chairs, the exhibitors, the International Advisory Board, the media, the KKL staff and Lucerne Incoming for the registration services. Finally, we thank all of you for your coming. May we all have a wonderful week in Lucerne with fruitful technical debates and personal exchanges! ….and the next chances to enjoy Lucerne as scientific and technical exchange platform will come in 2013:

- The 4th EUROPEAN PEFC & H2 FORUM will take place from the 2nd to 5th July 2013, chaired by Prof. Dr. Deborah Jones from Université de Montpellier, France.
- High temperature electroceramic technologies will be core topic again at the 11th EUROPEAN SOFC & SOE FORUM 2014 from the 1st to 4th July 2014.

Yours sincerely

Olivier Bucheli & Michael Spirig

Conference Session Overview

Session	**Luzerner Saal** (ground floor)	Session	**Auditorium** (1st floor)
A01	**Plenary 1** - Opening Session & International Overview		
A02	**Plenary 2** - International Overview		
A03	in **Club Rooms 3-8** (2nd floor) Poster Session I with topics from Sessions **A04, A05, A07, A09, A10, B10*, A11, A12, A13** * from Session II		
A04	Company & Major groups development status I (EU)	**B04**	Cell materials development I
A05	Company & Major groups development status II (WW)	**B05**	Diagnostic, advanced characterisation & modelling I
A06	**Plenary 3** - Advanced Characterisation and Diagnosis		
A07	Cell and stack design I	**B07**	SOE cell material development
A08	in **Club Rooms 3-8** (2nd floor) Poster Session II with topics from Sessions **B04, B05, B07, B09, *, B11, B12, B13** * in Session I		
A09	Cell and stack design II (Metal Supported Cells)	**B09**	Cell materials development II (IT & Proton Conducting SOFC)
A10	Cell operation	**B10**	Diagnostic, advanced characterisation & modelling II
A11	SOE cell and stack operation	**B11**	Fuels bio reforming
A12	Cell and stack operation	**B12**	Interconnects, coatings & seals
A13	Stack integration, system operation and modelling	**B13**	Seals
A14	**Plenary 4** - SOFC for Distributed Power Generation		
A15	**Plenary 5** - Closing Ceremony		

Chair's Welcome to 10th European SOFC Forum 2012

Chairwoman: Dr. Florence Lefebvre-Joud

CEA-LITEN, Grenoble, France
17, rue des Martyrs
38054 Grenoble Cedex 9 / France

Dear participant,

I am very pleased to welcome you to the 10th EUROPEAN SOFC FORUM 2012 in the beautiful city of Lucerne.

The conference encompasses this year several **Solid Oxide technologies**: **SOFC** (Fuel cell), **SOE** (Electrolyser), and **PCFC** (Proton Conductor ceramic Fuel Cells). The conference has been organised in order to give you a complete overview of their current status from material development, components optimisation, systems operation, either as fuel cell or as electrolyser, to their market entry and commercialisation possibilities. During 3 days, closed to 300 contributions will be presented in 21 oral sessions and in 2 poster sessions. They will consist of program overviews, scientific lectures and full-size system operation feedbacks. Thanks to the exhibition, updated product demonstrations will complement the program.

As we have entered a time where **energy efficiency is no more an option but a priority**, high temperature electrochemical converters based on solid oxide technologies can offer **extremely high electrical and thermal efficiencies** and in addition **high operation flexibility.**

Several **early markets deployments of SOFC** have already started and their status will be presented during this forum. Nevertheless, there are still challenges to solve for bridging the gap between a most promising technology and a mature proven one with **appropriate technological readiness level for today's markets**. These are for example the development of system management tools with relevant sensors, data analysis protocols and algorithms in order to control the lifetime expectancy of running SOFC or SOE systems, the development of accelerated tests to assess stack and system reliability in real operation conditions based on demo projects feedback, the development of in situ advanced characterisation means in order to better understand the parameters controlling stack performances and durability, etc.

Owing to the low production volume of SOFC, their cost still constitutes a barrier to their deployment. **Reinforced material R&D** is one preferred way to reduce significantly component's costs by making them reaching higher tolerance to impurities or pollutants, improved mechanical properties, wider acceptable operation conditions, etc. Finally, if SOFC and SOE market entry requires further technical improvements, it is also conditioned by the development of **new business models, dedicated value chains** and incentives to start moving forwards a real sustainable energy landscape.

In this fascinating context, I wish the European Fuel Cell Forum 2012 will catalyse fruitful dialogues between science, engineering, industry and market stakeholders, and I wish you successful and inspiring exchanges for further scientific and technical innovation work.

To conclude, I would like to address warm thanks to the Scientific Advisory and Organising Committees for their help in evaluating and ranking all received contributions and for building the current program with me. I would also like to thank the local organisers Michael Spirig and Olivier Bucheli for their friendly and highly efficient assistance.

Yours sincerely,

Florence Lefebvre-Joud

Conference Schedule and Program

Wednesday, June 27, 2012

Morning **Luzerner Saal** (ground floor) **Morning**

09:00	**Opening Session** **Plenary 1 - International Overview** *Chair: Florence Lefebvre-Joud / Olivier Bucheli*	**A01**
09:00	**Welcome by the Organizers** Olivier Bucheli, Michael Spirig European Fuel Cell Forum; Luzern/Switzerland	A0101
09:05	**Welcome by the Chairwoman** Florence Lefebvre-Joud CEA/Liten; Grenoble/France	A0102
09:15	**Welcome to Switzerland the Smart Research Place** Rolf Schmitz Swiss Federal Office of Energy SFOE; Bern/Switzerland	A0103
09:30	**The Status of SOFC Programs in USA - 2012** Daniel Driscoll, Briggs M. White U.S. DOE National Energy Technology Laboratory; Morgantown/USA	A0104
10:00	**Current SOFC Development in China: Challenges and Solutions for SOFC Technologies** Wei Guo Wang Fuel Cell and Energy Technology Division, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences; Ningbo/China	A0105
10:30	**Intermittence** with Refreshments served on Ground Floor in the Exhibition	

International Board of Advisors

- **Prof. Robert Steinberger (Chair; FZJ / Germany)**
- Prof. Frano Barbir (Unido/Ichet / Croatia)
- Dr. Ulf Bossel (ALMUS AG / Switzerland)
- Dr. Niels Christiansen (TOFC / Danmark)
- Dr. Karl Föger (Ceramic Fuel Cells / Australia)
- Prof. Angelika Heinzel (ZBT / Germany)
- Prof. Ellen Ivers-Tiffée (KIT / Germany)
- Prof. Deborah Jones (CNRS / France)
- Prof. John A. Kilner (Imperial College London / United Kingdom)
- Dr. Jari Kiviaho (VTT / Finland)
- Dr. Ruey-yi Lee (INER / Taiwan)
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- Dr. Günter Schiller (DLR Stuttgart / Germany)
- Dr. Subhash Singhal (Pacific Northwest National Laboratory / USA)
- Dr. Martin Smith (Uni St. Andrews / United Kingdom)
- Prof. Constantinos Vayenas (University of Patras / Greece)
- Prof. Martin Winter (Uni Münster / Germany)
- Dr. Christian Wunderlich (IKTS / Germany)

Wednesday, June 26, 2012

Morning **Luzerner Saal** (ground floor) **Morning**

11:00	**Plenary 2 - International Overview** *Chair: Florence Lefebvre-Joud / Olivier Bucheli*	**A02**	
11:00	**Europe's Fuel Cells and Hydrogen Joint Undertaking** Bert de Colvaneer FCH JU; Brussels/EU	A0201	
11:30	**Commercialization of SOFC m-CHP in the Japanese Market** M. Atsushi Nanjou, Mr. Yamaguchi , Tomonari Komiyama, Toshiya Nakahara JX Nippon Oil & Energy Corporation; Tokyo/Japan	A0202	
12:00	**High Temperature Fuel Cell Activities in Korea** Nigel Sammes, Jong-Shik Chung POSTECH; Pohang/South Korea	A0203	
12:30	**Lunch Break** → Lunch is served on 2nd Floor - Terrace → Coffee is served on Ground Floor in the Exhibition		

Afternoon **Club Room 3-8** (2nd floor) **Afternoon**

13:30	**Poster Session I** *Florence Lefebvre-Joud / Julie Mougin / Etienne Bouyer* Posters of sessions **A04, A05, A07, A09, A10, B10*, A11, A12, A13**	**A03**	see page I-25 ff *exception

Wednesday, June 27, 2012

Afternoon | **Luzerner Saal** (ground floor) | **Auditorium** (1st floor) | Afternoon

14:30	**Company & Major groups development status I (EU)** *Chair: Wei Guo Wang / Daniel Driscoll*	**A04**	**Cell materials development I** *Chair: Nathalie Petigny / Prof Yokokawa*	**B04**
14:30	**SOFC System Development at AVL** Jürgen Rechberger, Michael Reissig, Martin Hauth, Peter Prenninger AVL List GmbH; Graz/Austria	A0401	**Fundamental Material Properties Underlying Solid Oxide Electrochemistry** Mogens Mogensen, Karin Vels Hansen, Peter Holtappels, Torben Jacobsen Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, DTU; Roskilde/Denmark	B0401
14:45	**Status of the Solid Oxide Fuel Cell Development at Topsoe Fuel cell A/S and Risø DTU** Niels Christiansen (1), Søren Primdahl (1), Marie Wandel (2), Severine Ramousse (2), Anke Hagen (2) (1) Topsoe Fuel Cell A/S; Lyngby/Denmark (2)Department of Energy Conversion and Storage, Technical University of Denmark; Roskilde / Denmark	A0402	**La and Ca doped SrTiO3: A new A-site deficient strontium titanate in SOFC anodes** Maarten C. Verbraeken (1), Boris Iwanschitz (2), Andreas Mai (2), John T.S. Irvine (1) (1) University of St Andrews, School of Chemistry; St Andrews/UK (2) Hexis AG; Winterthur/Schweiz	B0402
15:00	**Progress in the Development of the Hexis' SOFC Stack and the Galileo 1000 N Micro-CHP System** Andreas Mai, Boris Iwanschitz, Roland Denzler, Ueli Weissen, Dirk Haberstock, Volker Nerlich, Alexander Schuler Hexis Ltd.; Winterthur/Switzerland	A0403	**Thermomechanical Properties of Re-oxidation Stable Y-SrTiO3 Ceramic Anode Substrate Material** Viacheslav Vasechko, Bingxin Huang, Qianli Ma, Frank Tietz, Jürgen Malzbender Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany	B0403
15:15	**Development and Manufacturing of SOFC-based products at SOFCpower SpA** Massimo Bertoldi (1), Olivier Bucheli (2), Stefano Modena (1), Alberto V. Ravagni (1) (2) (1) SOFCpower SpA; Pergine Valsugana/Italy (2) HTceramix SA, Yverdon-les-Bains / Switzerland	A0404	**Doped La2-XAXNi1-YBYO4+ δ (A=Pr, Nd, B=Co, Zr, Y) as IT-SOFC cathode** Laura Navarrete, María Fabuel, Cecilia Solís, José M. Serra Instituto de Tecnología Química (Universidad Politécnica de Valencia - Consejo Superior de Investigaciones Científicas); Valencia/Spain	B0404

15:30	**Recent Results in JÜLICH SOFC Technology Development** Ludger Blum (1), Bert de Haart (1), Jürgen Malzbender (1), Norbert H. Menzler (1), Josef Remmel (2), Robert Steinberger-Wilckens (3) (1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany (2) Forschungszentrum Jülich GmbH, Central Institute of Technology (ZAT); Jülich/Germany (3) University of Birmingham, School of Chemical Engineering, Birmingham/UK	A0405	**Development and Characterization of LSCF/CGO composite cathodes for SOFCs** Rémi Costa (1)*, Roberto Spotorno (1), Norbert Wagner (1), Zeynep Ilhan (1), Vitaliy Yurkiv (1), (2), Wolfgang G. Bessler (1), (2), Asif Ansar (1) (1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany (2) Universität Stuttgart, Institute of Thermodynamics and Thermal Engineering (ITW); Stuttgart/Germany	B0405
15:45	**Compact and highly efficient SOFC Systems for off-grid power solutions** Matthias Boltze, Gregor Holstermann, Arne Sommerfeld, Alexander Herzog new enerday GmbH; Neubrandenbur/Germany	A0406	**Effect of Ultra-thin Zirconia Blocking Layer on Performance of 1 µm-thick Gadolinia-doped Ceria Electrolyte SOFC** Doo-Hwan Myung (1), (2), Jongill Hong (2) , Kyungjoong Yoon (1), Byung-Kook Kim (1), Hae-Weon Lee (1), Jong-Ho Lee (1), Ji-Won Son (1) (1) Korea Institute of Science and Technology, High-Temperature Energy Materials Research Center; Seoul/South Korea (2) Yonsei University, Department of Materials Science and Engineering; Seoul/South Korea	B0406
16:00	**Intermittence** with Refreshments served on Ground Floor in the Exhibition			

Wednesday, June 27, 2012

Wednesday, June 27, 2012

Afternoon | **Luzerner Saal** (ground floor) | **Auditorium** (1st floor) | Afternoon

16:30	**Company & Major groups development status II (Worldwide)** *Chair: Matti Nopponen / John Irvine*	**A05**	**Diagnostic, advanced characterisation and modelling I** *Chair: Ellen Ivers-Tiffee / Alan Atkinson*	**B05**
16:30	**Latest Update on Delphi's Solid Oxide Fuel Cell Stack for Transportation and Stationary Applications** Karl Haltiner, Rick Kerr Delphi Corporation; W. Henrietta/USA-NY	A0501	**Stroboscopic Ni Growth/Volatilization Picture** J. Andreas Schuler (1), Boris Iwanschitz (2), Lorenz Holzer (3), Marco Cantoni (4),Thomas Graule (1) (1) EMPA; Dübendorf/Switzerland (2) Hexis AG; Winterthur/Switzerland (3) ZHAW; Winterthur/Switzerland (4) EPFL; Lausanne/Switzerland	B0501
16:45	**Solid Oxide Fuel Cell Developmentat at Versa Power Systems** Brian Borglum, Eric Tang, Michael Pastula Versa Power Systems; Calgary AB/Canada	A0502	**Oxidation of nickel in solid oxide fuel cell anodes: A 2D kinetic modeling approach** Jonathan P. Neidhardt (1), (2), Wolfgang G. Bessler (1), (2) (1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany (2) Stuttgart University, Institute of Thermodynamics and Thermal Engineering (ITW); Stuttgart/Germany	B0502
17:00	**BlueGen for Europe – Commercialisation of Ceramic Fuel Cells' residential SOFC Product** Karl Föger Ceramic Fuel Cells BV; RK Heerlen/Netherlands	A0503	**Nickel oxide reduction studied by environmental TEM** Q. Jeangros (1)*, T.W. Hansen (2) , J.B. Wagner (2) , C.D. Damsgaard (2), R.E. Dunin-Borkowski (3), J. Van herle (4), A. Hessler-Wyser (1) (1) EPFL, Interdisciplinary Centre for Electron Microscopy; Lausanne/Switzerland (2) DTU, Center for Electron Nanoscopy; Lyngby/Denmark (3) Jülich Research Centre, Ernst Ruska-Centre; Jülich/Germany (4) EPFL; Laboratory for Industrial Energy Systems; Lausanne/Switzerland	B0503

17:15	**SOFC system integration activities in NIMTE** Shuang Ye, Jun Peng, Bin Wang, Sai Hu Chen, Qin Wang, Wei Guo Wang Chinese Academy of Sciences, Fuel Cell and Energy Technology Division, Ningbo Institute of Materials Technology and Engineering; Ningbo/China	A0504	**LEIS of Oxide Air Electrode Surfaces** John Kilner (1) (2), Matthew Sharp (1), Stuart Cook (1), Helena Tellez (1), Monica Burriel (1) and John Druce (2) (1) Imperial College London, Department of Materials; London/UK (2) International Institute of Carbon Neutral research (I2CNER), Kyushu University, Fukuoka/Japan	B0504
17:30	**Development of SOFC Technology at INER** Ruey-yi Lee, Yung-Neng Cheng, Chang-Sing Hwang, Maw-Chwain Lee Institute of Nuclear Energy Research; Longtan Township/Taiwan ROC	A0505	**Impact of Surface-related Effects on the Oxygen Exchange Kinetics of IT-SOFC Cathodes** Edith Bucher, Wolfgang Preis (1), Werner Sitte (1), Christian Gspan (2), Ferdinand Hofer (2) (1) Montanuniversität Leoben, Chair of Physical Chemistry; Leoben/Austria (2) Institute for Electron Microscopy and Fine Structure Research (FELMI), Graz University of Technology & Graz Center for Electron Microscopy (ZFE); Graz/Austria	B0505
17:45	**Techno-economical analysis of systems converting CO2 and H2O into liquid fuels including high-temperature steam electrolysis** Christian von Olshausen, Dietmar Rüger sunfire GmbH; Dresden/Germany	A0506	**Anisotropy of the oxygen diffusion in Ln2NiO4+d (Ln=La, Nd, Pr) single crystals** Jean-Marc Bassat (1), Mónica Burriel (2) , Rémi Castaing (1), (2) , Olivia Wahyudi (1), Philippe Veber (1), Isabelle Weill (1), Mustapha Zaghrioui (4),Monica Cerreti (3), Antoine Villesuzanne (1), Werner Paulus (3), Jean-Claude Grenier (1) and John A. Kilner (2) (1) Université de Bordeaux, CNRS, ICMCB; Pessac Cedex/France (2) Imperial College London, Department of Materials; London/UK (3) Institut Charles Gerhardt (ICG), UMR 5253, Montpellier/France (4) LEMA, UMR 6157-CNRS-CEA, IUT de Blois, Blois/France	B0506
18:00	**End of Sessions**			
18:30	**Swiss Surprise** Local developments and showplace focused evening program Extra registered participants **meet at the Lakeside of KKL, around the large Fountain**			

Afternoon **Luzerner Saal** (ground floor) **Auditorium** (1st floor) Afternoon

Wednesday, June 27, 2012

Thursday, June 28, 2012

09:00	**Plenary 3 - Advanced Characterisation and Diagnosis** *Chair: John Kilner*	**A06**
09:00	**Studies of Solid Oxide Fuel Cell Electrode Evolution Using 3D Tomography** Scott A Barnett, J Scott Cronin, Kyle Yakal-Kremski Northwestern University, Department of Materials Science; Evanston/USA-IL	A0601
09:30	**Electrochemical Impedance Spectroscopy: A Key Tool for SOFC Development** André Leonide (1), André Weber (2), Ellen Ivers-Tiffée (2) (1) Siemens AG, CT T DE HW4; Erlangen/Germany (2) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe / Germany	A0602
10:00	**In-operando Raman spectroscopy of carbon deposition from Carbon Monoxide and Syngas on SOFC nickel anodes** Gregory J Offer (1), Robert C Maher (2) , Vladislav Duboviks (1), Edward Brightman (1), Lesley F Cohen (2) and Nigel P Brandon (1) (1) Imperial College London, Department of Earth Science Engineering and; London/UK (2) Department of Physics, Imperial College London, London/UK	A0603
10:30	**Intermittence** with Refreshments served on Ground Floor in the Exhibition	

Scientific Advisory Committee

- **Dr. Florence Lefebvre-Joud, CEA, Grenoble, France (Chair)**
- Dr. John Boegild Hansen, Haldor Topsoe, Denmark
- Dr. Annabelle Brisse, EIfER, Karlsruhe,Germany
- Dr. Agata Godula-Jopek, EADS Innovation Works, Munich, Germany
- Prof. Jean Claude Grenier, ICMCB, Bordeaux, France
- Dr. Anke Hagen Risoe Nat. Lab. / DTU, Roskilde, Denmark
- Prof. John T.S. Irvine, University of St. Andrews, UK
- Prof. Ellen Ivers-Tiffée, Karlsruhe Institute of Technology, Germany
- Prof. John A. Kilner, Imperial College London, London, UK
- Dr. Matti Noponen, Wartsila, Finlande
- Dr. Nathalie Petigny, Saint Gobain, Cavaillon, France,
- Dr. Lide Rodriguez, Ikerlan, Mondragon, Spain
- Dr. Massimo Santarelli, PoliTo,Torino, Italy
- Dr. Robert Steinberger-Wilckens, FZ Jülich, Jülich, Germany
- Dr. Jan Van herle, EPFL, Lausanne, Switzerland

The Scientific Advisory Committee has been formed to structure the technical program of the 10th EUROPEAN SOFC FORUM 2012. This panel has exercised full scientific independence in all technical matters.

Thursday, June 28, 2012

Morning **Luzerner Saal** (ground floor) **Auditorium** (1st floor) Morning

11:00	Cell and stack design I *Chair: Lide Rodriguez / Niels Christiansen*	A07	SOE cell material development *Chair: Annabelle Brisse / Ludger Blum*	B07
11:00	**Co-sintering of Solid Oxide Fuel Cells made by Aqueous Tape Casting** Johanna Stiernstedta,b, Elis Carlström a, Bengt-Erik Mellanderb (1) Swerea IVF AB; Mölndal/Sweden (2) Chalmers University of Technology, Department of Applied Physics; Göteborg/Sweden	A0701	**Step-change in (La,Sr)(M,Ti)O3 solid oxide electrolysis cell cathode performance with exsolution of B-site cations** George Tsekouras, Dragos Neagu, John T.S. Irvine University of St Andrews, School of Chemistry; St Andrews/UK	B0701
11:15	**Powder Injection Molding of Structured Anode-supported Solid Oxide Fuel Cell** Antonin Faes (1), Amédée Zryd (1), Hervé Girard (1), Efrain Carreño-Morelli (1), Zacharie Wuillemin (2), Jan Van Herle (3) (1) University of Applied Science Western Switzerland, Design and Materials Unit; Sion/Switzerland (2) HTceramix – SOFCpower, Yverdon-les-Bains/Switzerland (3) Laboratory of Industrial Energy Systems (LENI), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne/Switzerland	A0702	**Enhanced Performances of Structured Oxygen Electrode for High Temperature Steam Electrolysis** Tiphaine Ogier (1), Jean-Marc Bassat (1), Fabrice Mauvy (1), Sébastien Fourcade (1), Jean-Claude Grenier(1), Karine Couturier (2), Marie Petitjean (2), Julie Mougin (2) (1) Université de Bordeaux, CNRS, ICMCB; Pessac Cedex/France (2) CEA-Grenoble, LITEN/DTBH/LTH; Grenoble Cedex 9/ France	B0702
11:30	**Inkjet Printing of Segmented-in-Series Solid-Oxide Fuel Cell Architectures** Wade Rosensteel (1), Nicolaus Faino (1), Brian Gorman (2), Neal P. Sullivan (1) (1) Colorado School of Mines, Colorado Fuel Cell Center, Mechanical Engineering Department; Golden/USA-CO (2) Colorado Fuel Cell Center, Colorado School of Mines, Metallurgical and Materials Engineering Department; Golden/USA-CO	A0703	**Electrochemical Characterisation of High Temperature Solid Oxide Electrolysis Cell Based on Scandia Stabilized Zirconia with Enhanced Electrode Performance** Nikolai Trofimenko, Mihails Kusnezoff, Alexander Michaelis Fraunhofer IKTS; Dresden/Germany	B0703
11:45	**Miniaturized free-standing SOFC membranes on silicon chips** M. Prestat (1), A. Evans (1), R. Tölke (1), M.V.F. Schlupp (1), B. Scherrer (1), Z. Yáng (1), J. Martynczuk (1), O. Pecho (1), H. Ma (1), A. Bieberle-Hütter (1), L.J. Gauckler (1), Y. Safa (2), T. Hocker (2), L. Holzer (2), P. Muralt (3), Y. Yan (3) ,J. Courbat (4), D. Briand (4), N.F. de Rooij (4)	A0704	**Durability studies of Solid Oxide Electrolysis Cells (SOEC)** Aurore Mansuy (1) (2), Julie Mougin (1), Marie Petitjean (1), Fabrice Mauvy (2) (1) CEA Grenoble LITEN/DTBH/LTH; Grenoble/France (2) CNRS, Université de Bordeaux, ICMCB, Pessac/France	B0704

	(1) ETH Zurich, Nonmetallic Inorganic Materials; Zurich/Switzerland (2) Zurich University of Applied Sciences (ZHAW), Institute for Computational Physics; Winterthur/Switzerland (3) EPFL, Ceramics Laboratory; Lausanne/Switzerland (4) EPFL, Sensors, Actuators and Microsystems Laboratory; Neuchâtel/Switzerland			
12:00	**Large-area micro SOFC based on a silicon supporting grid** Iñigo Garbayo (1), Marc Salleras (1), Albert Tarancón (2) , Alex Morata (2), Guillaume Sauthier (3), Jose Santiso (3), Neus Sabaté (1) (1) Institute of Microelectronics of Barcelona (IMB-CNM, CSIC); (2) Catalonia Institute for Energy Research (IREC); (3) Research Centre of Nanoscience and Nanotechnology (CIN2,CSIC) Barcelona/Spain	A0705	**Influence of steam supply homogeneity on electrochemical durability of SOEC** Manon Nuzzo (1), Julien Vulliet (1), Anne Laure Sauvet (1), Armelle Ringuedé (2) (1) CEA Le Ripault; Monts/France (2) LECIME, UMR 7575 CNRS, ENSCP, Chimie Paristech; Paris/France	B0705
12:15	**Fabrication and Performance of Nd1.95NiO4+δ (NNO) Cathode supported Microtubular Solid Oxide Fuel Cells** Miguel A. Laguna-Bercero (1), Jorge Silva (1), R. Campana (1) (3), Henning Luebbe (2), Jan Van Herle (2) (1) Universidad de Zaragoz, Instituto de Ciencia de Materiales de Aragón; Zaragoza/Spain (2) EPFL, Industrial Energy Systems Laboratory (LENI); Lausanne/Switzerland (3) Centro Nacional del Hidrógeno; Puertollano /Spain	A0706	**High Temperature Electrolysis at EIFER** A. Brisse, J. Schefold EIFER; Karlsruhe/Germany	B0706
12:30	**Lunch Break** → Lunch is served on 2nd Floor - Terrace → Coffee is served on Ground Floor in the Exhibition			

Morning **Luzerner Saal** (ground floor) **Auditorium** (1st floor) **Morning**

Thursday, June 28, 2012

Afternoon **Club Room 3-8** (2nd floor) **Afternoon**

13:30	**Poster Session II** *Florence Lefebvre-Joud / Julie Mougin / Etienne Bouyer* Posters of sessions **B04, B05, B07, B09, *, B11, B12, B13**	**A08**	see page I-25 ff *exception part of Poster Session I

Thursday, June 28, 2012

Afternoon **Luzerner Saal** (ground floor) **Auditorium** (1st floor) Afternoon

14:30 Cell and stack design II (Metal Supported Cells) — A09

Chair: Julie Mougin / Zacharie Willemin

14:30 — A0901

Micro-SOFC supported on a porous Ni film

Younki Lee, Gyeong Man Choi
Pohang University of Science and Technology (POSTECH), Fuel Cell Research Center and Department of Materials Science and Engineering; Pohang/South Korea

14:45 — A0902

Thin Electrolytes on Metal-Supported Cells

S. Vieweger (1), R. Mücke (1), N. H. Menzler (1), M. Rüttinger (2), Th. Franco (2), H.P. Buchkremer (1).
(1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany
(2) PLANSEE SE Innovation Services; Reutte/Austria

15:00 — A0903

Advances in Metal Supported Cells in the METSOFC EU Consortium

Brandon J. McKennaa, Niels Christiansena, Richard Schauperlb, Peter Prenningerb, Peter Blennowc, Trine Klemensøc, Severine Ramoussec
(1) Topsoe Fuel Cell A/S; Lyngby/Denmark
(2) AVL List Gmbh; Graz/Austria
(3) Risø DTU; Roskilde/Denmark

14:30 Cell materials development II (IT & Proton Conducting SOFC) — B09

Chair: Jean Claude Grenier / Mogens Mogensen

14:30 — B0901

Nanostructured Electrodes forLow-Temperature Solid Oxide Fuel Cells

Zhongliang Zhan, Da Han, Tianzhi Wu, Shaorong Wang, Tinglian Wen
Chinese Academy of Sciences (SICCAS), Shanghai Institute of Ceramics, CAS Key Laboratory of Materials for Energy Conversion; Shanghai/China

14:45 — B0902

Protonic Ceramic Fuel Cells based on reactive sintered BaCe0.2Zr0.7Y0.1O3-δ electrolytes

Shay Robinson (1), Anthony Manerbino (1), (2) , Sean Babinec (1), Neal P Sullivan (1), Jianhua Tong (1), W. Grover Coors (1), (2)
(1) Colorado School of Mines, Department of Mechanical Engineering, Colorado Fuel Cell Center; Golden/USA-CO
(2) CoorsTek Inc.; Golden/USA-CO

15:00 — B0903

ITSOFC based on innovative electrolyte and electrodes materials

Messaoud Benhamira (1), Annelise Brüll (2) , Anne Morandi (4) , Marika Letilly (1), Annie Le Gal La Salle (1), Jean-Marc Bassat (2), Jaouad Salmi (3), Richard Laucournet (5), Maria-Teresa Caldes (1), Mathieu Marrony (4), Olivier Joubert (1)
(1) Institut des Matériaux Jean Rouxel (IMN); Nantes cedex 3/France;
(2) Institut de Chimie de la Matière Condensée de Bordeaux (ICMCB); PESSAC Cedex/France
(3) Marion Technologie (MT); Verniolle/France
(4) European Institute for Energy Research (EIfER); Karlsruhe/Germany
(5) CEA-Grenoble/LITEN/DTBH/LTH; Grenoble cedex 9/France

15:15	**Stack Tests of Metal-Supported Plasma-Sprayed SOFC** Patric Szabo (1), Asif Ansar (1), Thomas Franco (2) , Malko Gindrat (3), Thomas Kiefer (4) (1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany (2) PLANSEE SE; Reutte/Austria (3) Sulzer Metco AG; Wohlen/Switzerland (4) ElringKlinger AG; Dettingen, Erms / Germany	A0904	**New Cercer Cathodes of Electronic and Protonic Conducting Ceramic Composites for Proton Conducting Solid Oxide Fuel Cells** Cecilia Solís, Vicente B. Vert, María Fabuel, Laura Navarrete (1), José M. Serra (1), Francesco Bozza (2), Nikolaos Bonanos (2) (1) Universidad Politécnica de Valencia, Instituto de Tecnología Química; Valencia/Spain (2) DTU, Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Department; Roskilde/Denmark	B0904
15:30	**Tubular metal supported solid oxide fuel cell resistant to high fuel utilization** Lide M. Rodriguez-Martinez, Laida Otaegi, Amaia Arregi, Mario A. Alvarez, Igor Villarreal Ikerlan, Centro Tecnológico; Álava/Spain	A0905	**Cathode Materials for Low Temperature Protonic Oxide Fuel Cells** M.D. Sharp, S. N. Cook, J.A. Kilner Imperial College London, Department of Materials; London/UK	B0905
15:45	**Development and Industrialization of Metal-Supported Solid Oxide Fuel Cells** Thomas Franco (1), R. Mücke (2) , A. Weber (3), M. Rüttinger (1), M. Haydn (1), N.H. Menzler (2), A. Venskutonis (1), H.P. Buchkremer (2), L. S. Sigl (1) (1) PLANSEE SE, Innovation Services; Reutte/Austria (2) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research; Jülich/Germany (3) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany	A0906	**Characterization of PCFC-Electrolytes Deposited by Reactive Magnetron Sputtering and comparison with their pellet samples** Mohammad Arab Pour Yazdi (1)*, Pascal Briois (1), Lei Yu (3), Samuel Georges (3), Remi Costa (4), Alain Billard (1,2) (1) LERMPS-UTBM; Belfort cedex/France (2) LEPMI, INPG, ENSEEG; Saint Martin d'Hères Cedex/France	B0906
16:00	**Intermittence** with Refreshments served on Ground Floor in the Exhibition			

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Afternoon **Luzerner Saal** (ground floor) **Auditorium** (1st floor) Afternoon

16:30	**Cell operation** *Chair : Anke Hagen / Kazunari Sasaki*	**A10**	**Diagnostic, advanced characterisation and modelling II** *Chair : Jan Van Herle / Scott barnett*	**B10**
16:30	**Ni-agglomeration in Solid Oxide Fuel Cells under different operating conditions** Boris Iwanschitz (1), Lorenz Holzer (2), Andreas Mai (1), Michael Schütze (3) (1) Hexis AG.; Winterthur /Switzerland (2) ZHAW (ICP); Winterthur/Switzland (3) DECHEMA-Forschungsinstitut; Frankfurt / Germany	A1001	**Elementary Kinetics and Mass Transport in LSCF-Based Cathodes: Modeling and Experimental Validation** Vitaliy Yurkiv (1), (2), Rémi Costa, (1), Zeynep Ilhan (1), Asif Ansar (1), Wolfgang G. Bessler (1), (2) (1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany (2) Universität Stuttgart, Institute of Thermodynamics and Thermal Engineering (ITW); Stuttgart/Germany	B1001
16:45	**Durability and Performance of High Performance Infiltration Cathodes** Martin Søgaard, Alfred J. Samson, Nikolaos Bonanos, Johan Hjelm, Per Hjalmarsson, Søren P. V. Foghmoes, Tânia Ramos Technical University of Denmark, Risø Campus, Department of Energy Conversion and Storage; Roskilde/Denmark	A1002	**Three Dimensional Microstructures and Mechanical Properties of Porous La0.6Sr0.4Co0.2Fe0.8O3−δ Cathodes** Zhangwei Chen, Xin Wang, Vineet Bhakhri, Finn Giuliani, Alan Atkinson Imperial College London, Department of Materials; London/UK	B1002
17:00	**Chromium Poisoning of LaMnO3-based Cathode within Generalized Approach** Harumi Yokokawa (1), Teruhisa Horita (1), Katsuhiko Yamaji (1), Haruo Kishimoto (1), Tohru Yamamoto (2), Masahiro Yoshikawa (2), Yoshihiro Mugikura (2), Tatsuo Kabata (3), Kazuo Tomida (3) (1) National Institute of Advanced Industrial Science and Technology, Energy Technology Research Institute; Ibaraki/Japan (2) Central Research Institute of Electric Power Industry(CRIEPI); Kanagawa/Japan 3) Mitsubishi Heavy Industry, Ltd.; Nagasaki/Japan	A1003	**3D Quantitative Characterization of Nickel-Yttria-stabilized Zirconia Solid Oxide Fuel Cell Anode Microstructure in Operation** Zhenjun Jiao, Naoki Shikazono, Nobuhide Kasagi University of Tokyo, Institute of Industrial Science; Tokyo/Japan	B1003

17:15	**Chromium poisoning of La0.6Sr0.4Co0.2Fe0.8 O3-δ in Solid Oxide Fuel Cells** Soo-Na Lee, Alan Atkinson, John A Kilner Imperial College London, Department of Materials; London/UK	A1004	**Mechanical Characteristics of Electrolytes assessed with Resonant Ultrasound Spectroscopy** Wakako Araki (1), Hidenori Azuma (1), Takahiro Yota (1), Yoshio Arai (1), Jürgen Malzbender (2) (1) Saitama University, Graduate School of Science and Engineering; Saitama/Japan (2) Forschungszentrum Jülich GmbH, IEK-2; Jülich/Germany	B1004
17:30	**Evaluation of Sulfur Dioxide Poisoning for LSCF Cathodes** Fangfang Wang, Katsuhiko Yamaji, Manuel E. Brito, Do-Hyung Cho, Taro Shimonosono, Mina Nishi, Haruo Kishimoto, Teruhisa Horita, Harumi Yokokawa National Institute of Advanced Industrial Science and Technology (AIST); Ibaraki/Japan	A1005	**Dynamic 3D FEM Model of mixed conducting SOFC Cathodes** Andreas Häffelin, Jochen Joos, Jan Hayd, Moses Ender, André Weber, Ellen Ivers-Tiffée Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany	B1005
17:45	**Reversibility of Cathode Degradation in Anode Supported Solid Oxide Fuel Cells** Cornelia Endler-Schuck (1), (2), André Leonide (1), André Weber (1), Ellen Ivers-Tiffée (1), (2) (1) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany (2) Karlsruher Institut für Technologie (KIT), DFG Center for Functional Nanostructures (CFN); Karlsruhe/Germany	A1006	**Detailed electrochemical characterisation of large SOFC stacks** R. R. Mosbæk (1), J. Hjelm (2), R. Barfod (2), J. Høgh (1), P. V. Hendriksen (1) (1) DTU Energy Conversion, Risø Campus; Frederiksborgvej/Denmark (2) Topsoe Fuel Cell A/S; Lyngby/Denmark	B1006
18:00	**End of Sessions**			
19:20	**Dinner on the Lake** 19.20 **Boarding - Lake side of KKL peer 5/6** - Back in Lucerne 23.30 (short stop in Brunnen ca. 21.45 for earlier return by train)			

Friday, June 29, 2012

Morning | **Luzerner Saal** (ground floor) | **Auditorium** (1st floor) | Morning

09:00	**SOE cell and stack operation** *Chair: Jari Kivihao / Brian Borglum*	**A11**	**Fuels bio reforming** *Chair: Agata Godula / Bert Rietveld*	**B11**
09:00	**High Temperature Co-electrolysis of Steam and CO2 in an SOC stack: Performance and Durability** Ming Chen (1)*, Jens Valdemar Thorvald Høgh (1), Jens Ulrik Nielsen (2) , Janet Jonna Bentzen (1), Sune Dalgaard Ebbesen (1), Peter Vang Hendriksen (1) (1) Department of Energy Conversion and Storage, Technical University of Denmark, Roskilde / Denmark; Roskilde/Denmark (2) Topsoe Fuel Cell A/S, Nymoellevej 66, DK-(2)800 Kgs. Lyngby / Denmark	A1101	**Electrochemistry of Reformate-Fuelled Anode-Supported SOFC** Alexander Kromp (1), André Leonide (1), André Weber (1), Ellen Ivers-Tiffée (1), (2) (1) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany (2) DFG Center for Functional Nanostructures (CFN), Karlsruher Institut für Technologie (KIT), D-76131 Karlsruhe / Germany	B1101
09:15	**4 kW Test of Solid Oxide Electrolysis Stacks with Advanced Electrode-Supported Cells** J.E. O'Brien (1), X. Zhang (1), G. K. Housley (1), L. Moore-McAteer (1), G. Tao (2) (1) Idaho National Laboratory; Idaho Falls/USA-ID (2) Materials and Systems Research, Inc.; Salt Lake City/USA-UT	A1102	**Reforming and SOFC system concept with electrical efficiencies higher than 50 %** Christian Spitta, Carsten Spieker, Angelika Heinzel ZBT GmbH; Duisburg/Germany	B1102
09:30	**Enhanced Performance and Durability of a High Temperature Steam Electrolysis stack** A. Chatroux, K. Couturier, M. Petitjean, M. Reytier, G.Gousseau, J. Mougin, F. Lefebvre-Joud CEA-Grenoble, LITEN; Grenoble/France	A1103	**Minimising the Sulphur Interactions with a SOFC Anode based on Cu-Ca Doped Ceria** Araceli Fuerte (1), Rita X. Valenzuela (1), María José Escudero (1), Loreto Daza (2) (1) Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT); Madrid/Spain (2) ICP-CSIC; Campus Cantoblanco; Madrid/Spain	B1103
09:45	**Electrolysis and Co-electrolysis performance of a SOEC short stack** Stefan Diethelm (1), Jan Van herle (1), Dario Montinaro (2), Olivier Bucheli (3) (1) Ecole Polytechnique Fédérale de Lausanne, STI-IGM-LENI; Lausanne/Switzerland (2) SOFCPOWER; Mezzolombardo/Italy (3) Htceramix; Yverdon-les-bains/Switzerland	A1104	**Gas Transport and Methane Internal-Reforming Chemistry in Ni-YSZ and Metallic Anode Supports** Amy E. Richards, Neal P. Sullivan Colorado School of Mines, Colorado Fuel Cell Center, Mechanical Engineering Department; Golden/USA-CO	B1104

10:00	**SOEC enabled Methanol Synthesis** John Bøgild Hansen (1), Claus Friis Petersen (1), Ib Dybkjær (1), Jens Ulrik Nielsen (2), Niels Christiansen (2) (1)Haldor Topsøe A/S; Lyngby/Denmark (2) Topsoe Fuel Cell A/S; Lyngby/Denmark	A1105	**High-efficient biogas electrification by an SOFC-system with combined steam & dry reforming** Jana Oelze, Ralph-Uwe Dietrich, Andreas Lindermeir Clausthaler Umwelttechnik-Institut GmbH; Clausthal-Zellerfeld/Germany	B1105
10:15	**Direct and Reversible Solid Oxide Fuel Cell Energy Systems** Nguyen Q. Minh Center for Energy Research, University of California, San Diego; La Jolla/USA-CA	A1106	**ADIABATIC PREREFORMING OF ULTRA-LOW SULFUR DIESEL: POTENTIAL FOR MARINE SOFC-SYSTEMS AND EXPERIMENTAL RESULTS** Pedro Nehter (1), Hassan Modarresi (1), Nils Kleinohl (2) , John Bøgild Hansen (3), Ansgar Bauschulte (2), Jörg vom Schloss (2), Klaus Lucka (2) (1) TOPSOE FUEL CELL; Lyngby/Denmark (2) Oel Waerme-Institut GmbH; Herzogenrath/Denmark (3) Halder Topsoe A/S; Lyngby/Denmark	B1106
10:30	**Intermittence** with Refreshments served on Ground Floor in the Exhibition			

Morning **Luzerner Saal** (ground floor) **Auditorium** (1st floor) **Morning**

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Morning — **Luzerner Saal** (ground floor) — **Auditorium** (1st floor) — Morning

11:00	**Cell and stack operation** *Chair: Robert Steinberger / Stefano Modena*	**A12**	**Interconnects, coatings & seals** *Chair: Uli Vogt / Armelle Ringuede*	**B12**
11:00	**Chemical Degradation of SOFCs: External impurity poisoning and internal diffusion-related phenomena** Kazunari Sasaki (1), (2), (3), (4), Kengo Haga (3) , Tomoo Yoshizumi (3) , Hiroaki Yoshitomi (3), Kota Miyoshi (3), Shunsuke Taniguchi (1) (2), Yusuke Shiratori (1) (2) (3) (4) Kyushu University, Fukuoka/Japan (1) Next-Generation Fuel Cell Research Center (2) International Research Center for Hydrogen Energy (3) Faculty of Engineering (4) International Institute for Carbon-Neutral Energy Research (WPI-I2CNER)	A1201	**SOFC Stack with Composite Interconnect** Sergey Somov, Heinz Nabielek Solid Cell, Inc.; Rochester/USA-NY	B1201
11:15	**Effect of pressure variation on power density and efficiency of solid oxide fuel cells** Moritz Henke, Caroline Willich, Christina Westner, Florian Leucht, Josef Kallo, K. Andreas Friedrich German Aerospace Center (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany	A1202	**Recent Development in Pre-coating of Stainless Strips for Interconnects at Sandvik Materials Technology** Håkan Holmberg, Mats W Lundberg, Jörgen Westlinder AB Sandvik Materials Technology, Surface Technology R&D Center; Sandviken/Sweden	B1202
11:30	**CFY-Stack: from electrolyte supported cells to high efficiency SOFC stacks** S. Megel (1), M. Kusnezoff (1), N.Trofimenko (1), V. Sauchuk (1), J. Schilm (1), J. Schöne (1), W. Beckert (1), A. Michaelis (1), C. Bienert (2), M. Brandner (2), A. Venskutonis (2), S. Skrabs (2), and L.S. Sigl (2). (1) Fraunhofer IKTS; Dresden/Germany (2) PLANSEE SE; Reutte/Austria	A1203	**Corrosion behaviour of steel interconnects and coating materials in solid oxide electrolysis cell (SOEC)** Ji Woo Kim (1), Cyril Rado (2), Aude Brevet (2), Seul Cham Kim (3), Yong Seok Choi (3), Karine Couturier (2), Florence Lefebvre-Joud (2), Kyu Hwan Oh (3), Ulrich F. Vogt (1), Andreas Züttel (1) (1) Swiss Federal Laboratories for Materials Science and Technology, Hydrogen and Energy; Dübendorf/Switzerland (2) CEA-Grenoble, LITEN; Grenoble Cedex 9/France (3) Seoul National university, Dept. of Materials Science and Engineering; Seoul/South Korea	B1203

11:45	**Development of Robust and Durable SOFC Stacks** RasmusG. Barfod, Kresten Juel Jensen, Thomas Heiredal-Clausen, Jeppe Rass-Hansen Topsoe Fuel Cell; Lyngby/Denmark	A1204	**Multifunctional nanocoatings on FeCr steels - influence on chromium volatilization and scale growth** J. Froitzheim, S. Canovic, R. Sachitanand, M. Nikumaa, J.E. Svensson The High Temperature Corrosion Centre, Chalmers University of Technology, Inorganic Environmental Chemistry; Göteborg/Sweden	B1204
12:00	**Long-term Testing of SOFC Stacks at Forschungszentrum Jülich** Ludger Blum, Ute Packbier, Izaak Vinke, L.G.J. (Bert) de Haart Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany	A1205	**Characterization of a Cobalt-Tungsten Interconnect Coating** Anders Harthoej (1), Tobias Holt (2), Michael Caspersen (1), Per Møller (1) (1) The Technical University of Denmark, Produktionstorvet ; Lyngby/Denmark (2) Topsoe Fuel Cell, Lyngby / Denmark	B1205
12:15	**Study on Durability of Flattened Tubular Segmented-in-Series Type SOFC Stacks** Kazuo Nakamura (1), Takaaki Somekawa (1), Kenjiro Fujita (1), Kenji Horiuchi (1), Yoshio Matsuzaki (1), Satoshi Yamashita (1), Harumi Yokokawa (2), Teruhisa Horita (2), Katsuhiko Yamaji (2), Haruo Kishimoto (2), Masahiro Yoshikawa (3), Tohru Yamamoto (3), Yoshihiro Mugikura (3), Satoshi Watanabe (4), Kazuhisa Sato (4), Toshiyuki Hashida (4), Tatsuya Kawada (4), Nobuhide Kasagi (5), Naoki Shikazono (5), Koichi Eguchi (6), Toshiaki Matsui (6), Kazunari Sasaki (7), Yusuke Shiratori (7) (1) Tokyo Gas Co., Ltd.; Tokyo/japan; Tokyo/Japan (2) National Institute of Advanced Industrial Science and Technology (AIST); Tokyo/Japan; (3) Central Research Institute of Electric Power Industry (CRIEPI); Tokyo/Japan; (4) Tohoku University; (5) The University of Tokyo; (6) Tohoku University; Tohoku/Japan; (7) Kyushu University; Kyushu/Japan	A1206	**Barium - free sealing materials for high chromium containing alloys** Dieter Gödeke (1), Ulf Dahlmann (2), Jens Suffner (1) (1) SCHOTT AG; BU Electronic Packaging; Landshut/Germany (2) Schott AG, Research & Technology Development, Mainz/Germany	B1206
12:30	**Lunch Break** → Lunch is served on 2nd Floor - Terrace → Coffee is served on 2nd Floor - Terrace			

Afternoon **Luzerner Saal** (ground floor) **Auditorium** (1st floor) **Afternoon**

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Afternoon **Luzerner Saal** (ground floor) **Auditorium** (1st floor) Afternoon

13:30	**Stack integration, system operation and modelling** *Chair: John Boegild / Stephane Hody*	**A13**	**Seals** *Chair: Andre Weber / Magali Reytier*	**B13**
13:30	**Coupling and thermal integration of a solid oxide fuel cell to a magnesium hydride tank** Baptiste Delhomme (1), (2), Andrea Lanzini (2) , Gustavo Adolfo Ortigoza-Villalba (2) , Patricia De Rango (1), Simeon Nachev (1), Philippe Marty (3), Massimo Santarelli (2) (1) Institut Néel - CRETA, CNRS, Grenoble/France; Grenoble/France (2) Politecnico di Torino, Dipartimento di Energetica; Torino/Italy (3) UJF-Grenoble1, INP/CNRS; Grenoble/France	A1301	**Damage and Failure of Silver Based Ceramic/Metal Joints for SOFC Stacks** Tim Bause (1), Moritz Pausch (2) , Jürgen Malzbender (1), Tilmann Beck (1), Lorenz Singheiser (1) (1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK-2); Jülich/Germany (2) ElringKlinger AG; Dettingen, Erms/Germany	B1301
13:45	**Effects of Multiple Stacks with Varying Performances in SOFC System** Matti Noponen, Topi Korhonen Wärtsilä, Fuel Cells; Espoo/Finland	A1302	**Development of barium aluminosilicate glass-ceramic sealants using a sol-gel route for SOFC application** J. Puig (1) (2), F.Ansart (1), P.Lenormand (1), L. Antoine (2), J. Dailly(3), R. Conradt (4), S. M. Gross (5), B. Cela (5) (1) CIRIMAT; Toulouse cedex 9/France (2)ADEME; Angers/France (3) EIFER, Universität Karlsruhe; Karlsruhe/Germany (4) GHI, RWTH Aachen; Aachen/Germany (5) ZAT, FZ Juelich GmbH; Jülich/Germany	B1302
14:00	**CFLC SOFC system tested at GDF SUEZ CRIGEN – thermal cycles, Electric Vehicle charging, and ageing** Stéphane Hody (1), Krzysztof Kanawka (1) (2) (1) GDF SUEZ, Research & Innovation Division, CRIGEN; Saint-Denis la Plaine cedex/France (2) ECONOVING International Chair in Eco-Innovation, REEDS International Centre for Research in Ecological Economics, Eco-Innovation and Tool Development for Sustainability, University of Versailles Saint Quentin-en-Yvelines; Guyancourt/France	A1303	**Strength Evaluation of Multilayer Glass-Ceramic Sealants** Beatriz Cela Greven (1) (2), Sonja M. Gross (1), Dirk Federmann (1), Reinhard Conradt (2) (1) Forschungszentrum Juelich GmbH, Central Institute for Technology; Jülich/Germany (2) RWTH-University Aachen, Department of Glass and Ceramic Composites, Institute of Mineral Engineering; Aachen/Germany	B1303

14:15	**Modeling of the Dynamic Behavior of a Solid Oxide Fuel Cell System with Diesel Reformer** Michael Dragon, Stephan Kabelac Leibniz Universität Hannover, Institute for Thermodynamics; Hannover/Germany	A1304	**Self-healing sealants as a solution for improved thermal cyclability of SOEC** Sandra Castanie (1), Daniel Coillot (1), François O Mear (1), Lionel Montage (1), Renaud Podor (2) (1) Université Lille Nord de France, Unité de Catalyse et Chimie du Solide; Villeneuve d'Ascq/France (2) CEA-CNRS-UM2-ENSCM, Institut de Chimie Séparative de Marcoule; Bagnols-sur-Cèze cedex/France	B1304
14:30	**System Concept and Process Layout for a Micro-CHP Unit based on Low Temperature SOFC** Thomas Pfeifer (1), Laura Nousch (1), Wieland Beckert (1), Dick Lieftink (2), Stefano Modena (3) (1) Fraunhofer Institute for Ceramic Technologies and Systems IKTS; Dresden/Germany (2) Hygear Fuel Cell Systems, EG Arnhem/The Netherlands (3) SOFCPower Spa, Mezzolombardo/Italy	A1305	**Long term stability of glasses in SOFC** Lars Christiansen, Jonathan Love, Thomas Ludwig, Nicolas Maier, David Selvey, Xiao Zheng Ceramic Fuel Cells Limited; Victoria/Australia	B1305
14:45	**Simple and robust biogas-fed SOFC system with 50 % electric efficiency – Modeling and experimental results** Marc Heddrich, Matthias Jahn, Alexander Michaelis, Ralf Näke, Aniko Weder Fraunhofer Institute for Ceramic Technologies and Systems, IKTS; Dresden/Germany	A1306	**Impact of thermal cycling in dual-atmosphere conditions on the microstructural stability of reactive air brazed metal/ceramic joints** Jörg Brandenberg (1), Bernd Kuhn (1), Tilmann Beck (1), L. Singheiser (1) Moritz Pausch (2), Uwe Maier (2), Stefan Hornauer (2) (1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany (2) ElringKlinger AG; Dettingen, Erms / Germany	B1306
15:00	**Intermittence** with Refreshments served on Ground Floor around Registration Desk & on 1st Floor in front of the Auditorium			

Afternoon **Luzerner Saal** (ground floor) **Auditorium** (1st floor) **Afternoon**

Friday, June 29, 2012

Friday, June 29, 2012

Afternoon **Luzerner Saal** (ground floor) Afternoon

15:30	**Plenary 4 - SOFC for Distributed Power Generation** *Chair: Florence Lefebvre-Joud*	**A14**
15:30	**SOFC for distributed power generation** Jonathan Lewis London/UK	A1401
16:00	**Plenary 5 - Closing Ceremony** *Chair: Florence Lefebvre-Joud / EFCF*	**A15**
16:00	**Summary by the Chairwoman** Florence Lefebvre-Joud CEA/Liten; Grenoble/France	A1501
16:12	**Information on Next EFCF:** **4th European PEFC* and H2 Forum 2013** ***including all low temperature fuel cells** Michael Spirig (1), Deborah Jones (2), Olivier Bucheli (1) (1) European Fuel Cell Forum; Luzern/Switzerland (2) Université de Montpelliere/France	A1502
16:24	**Friedrich Schönbein & Hermann Göhr Award of the Best Paper, Poster and Science Contribution and award of the Medal of Honour** Florence Lefebvre-Joud (1), Ulf Bossel (2) (1) CEA/Liten; Grenoble/France (2) European Fuel Cell Forum; Luzern/Switzerland	A1503
16:48	**Thank you and Closing by the Organizers** Olivier Bucheli, Michael Spirig European Fuel Cell Forum; Luzern/Switzerland	A1504
17:00	**End of Sessions – Conference of Conference**	

Scientific Organizing Committee

- **Dr. Florence Lefebvre-Joud, CEA-LITEN, Grenoble /France (Chair)**
- Dr. Etienne Bouyer, CEA-LITEN, Grenoble /France
- Dr. Jari Kiviaho, VTT, Espoo/ Finlande
- Dr. Jérôme Laurencin, CEA-LITEN, Grenoble /France
- Dr. François Le Naour, CEA-LITEN, Grenoble /France
- Dr. Julie Mougin, CEA-LITEN, Grenoble /France
- Dr. Marie Petitjean, CEA-LITEN, Grenoble /France

Wednesday, June 27, 2012

Afternoon | 13:30 - 14:30 | **Club Room 3-8** (2nd floor)

Thursday, June 28, 2012

13:30 - 14:30 | **Club Room 3-8** (2nd floor) | Afternoon

Poster Session

Poster Session I

Company & Major groups development status I (EU) — A04

Overview of status in the EU and European Hydrogen and Fuel Cell Projects — A0407
Marieke Reijalt
European Hydrogen Association (EHA); Brussels/Belgium

Company & Major groups development status II (Worldwide) — A05

Approach to Industrial SOFC Production in Russia — A0507
A. Rojdestvin (1), A. Stikhin (1), V. Fateev (2)
(1) JSC TVEL; Moscow/Russia
(2) NRC, Kurchatov Institute

Plenary 3 - Advanced Characterisation and Diagnosis — A06

Cell and stack design I — A07

Processing of graded anode-supported micro-tubular SOFCs via aqueous gel-casting — A0707
M. Morales, M.E. Navarro, X.G. Capdevila, M. Segarra
Universitat de Barcelona, Centre DIOPMA, Departament de Ciència dels Materials i Enginyeria Metal; Barcelona/Spain

Poster Session II

Cell materials development I — B04

Microstructural and electrochemical characterization of thin La0.6Sr0.4CoO3-δ cathodes deposited by spray pyrolysis — B0407
O. Pecho (1), (2), M. Prestat (3) , Z. Yáng (3) , J. Hwang (4), (5), J.-W. Son (4), L. Holzer (1), T. Hocker (1), J. Martynczuk (3), L.J. Gauckler (3)
(1) Zurich University of Applied Sciences (ZHAW), Institute for Computational Physics; Winterthur/Switzerland
(2) ETH Zurich, Institute for Building Materials; Zurich/Switzerland
(3) ETH Zurich, Nonmetallic Inorganic Materials Zurich/Switzerland
(4) Korea Institute of Science and Technology (KIST), High-Temperature Energy Materials Research Center; Seoul/South Korea
(5) Korea University, Department of Materials Science and Engineering; Seoul/South Korea

LaNi0.6Fe0.4O3 cathode performance on Ce0.9Gd0.1O2 electrolyte — B0408
M. Nishi, T. Horita, K. Yamaji, H. Yokokawa, H. Kishimoto, T. Shimonosono, F. Wang, D. H. Cho, Manuel E. Brito
National Institute of Advanced Industrial, Science and Technology (AIST); Higashi/Japan

Compatibility and Electrochemical Behavior of La2NiO4+δ on La0.8Sr0.2Ga0.8Mg0.2O3 — B0409
Lydia Fawcett, John Kilner, Stephen Skinner
Department of Materials, Imperial College London; London/UK

Poster Session

New Methods of Electrode Preparation for Micro-Tubular Solid Oxide Fuel Cells A0708
K.S. Howe (1), A. R. Hanifi (2) , K. Kendall (1), Thomas H. Etsell (2), Partha Sarkar (3)
(1) University of Birmingham, Centre for Hydrogen and Fuel Cell Research; Birmingham/UK
(2) University of Alberta, Department of Chemical & Materials Engineering; Edmonton/Canada
(3) Alberta Innovates - Technology Futures, Environment & Carbon Management; Edmonton/Canada

Sol-Gel Process to Prepare Hierarchical Mesoporous Thin Films Anode for Micro-SOFC A0709
Guillaume Müller (1), (4), Gianguido Baldinozzi (2), Marlu César Steil (3), Armelle Ringuedé (4), Christel Laberty-Robert (1), Clément Sanchez (1)
(1) Université Pierre et Marie Curie, LCMCP, Laboratoire Chimie de l(1) Matière Condensée de Paris; Paris/France;
(2) CEA-CNRS-Ecole Centrale Paris, Matériaux fonctionnels pour l'énergie; Châtenay-Malabry/France; (3) UMR INP-CNRS- 5279, Laboratoire d'Electrochimie et de Physicochimie des Matériaux et des Interfaces; Saint-Martin d'Hères/France, (4) UMR CNRS 7575, Chimie ParisTech, Laboratoire d'Electrochimie, Chimie des Interfaces et Modélisation pour l'Energie; Paris Cedex 05/France

Sr2Fe1.5Mo0.5O6-δ as symmetrical electrode for micro SOFC A0710
Iñigo Garbayo (1), Saranya Aruppukottai (2) , Guilhem Dezanneau (3) , Alex Morata (2), Neus Sabaté (1), Jose Santiso (4), Albert Tarancón (2)
(1) Institute of Microelectronics of Barcelona (IMB-CNM, CSIC); Barcelona/Spain
(2) Catalonia Institute for Energy Research (IREC); Barcelona/Spain
(3) Laboratoire Structures Propriétés et Modélisation des Solides (SPMS – ECP); Barcelona/Spain
(4) Research Centre of Nanoscience and Nanotechnology (CIN2, CSIC); Barcelona/Spain

Single Step Process for Cathode Supported half-cell B0410
Angela Gondolini (1), (2), Elisa Mercadelli (1), Paola Pinasco (1), Alessandra Sanson (1)
(1) National Council of Research, Institute of Science and Technology for Ceramics (ISTEC-CNR); Faenza (RA)/Italy
(2) University of Bologna, Department of Industrial Chemistry and Materials (INSTM); Bologna/Italy

Modified oxygen surface-exchange properties by nanoparticulate Co3O4 and SrO in La0.6Sr0.4CoO3-d thin-film cathodes B0411
Jan Hayd (1,2), André Weber (1), Ellen Ivers-Tiffée (1,2)
(1) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany
(2) Karlsruher Institut für Technologie (KIT), DFG Center for Functional Nanostructures (CFN); Karlsruhe/Germany

La10-xSrxSi6O26 coatings elaborated by DC magnetron sputtering for electrolyte application in SOFC technology B0412
P. Briois (1), S.Fourcade (2) , F.Mauvy (2) , J.C.Grenier (2), A.Billard (1)
(1) LERMPS-UTBM; Belfort cedex/France
(2) Univ. de Bordeaux; Bordeaux cedex/France

A review on thin layers processed by Atomic Layer Deposition for SOFC applications B0413
M. Cassir (1), A. Ringuedé (1), M. Tassé (1), B. Medina-Lotta (2), L. Niinistö (3)
(1) LECIME, Laboratoire d'Electrochimie; Paris/France
(2) Universidad Autónoma de Nuevo León, Facultad de Ingeniería Mecánica y Eléctrica; México/México
(3)Helsinki University of Technology (TKK), Laboratory of Inorganic and Analytical Chemistry; Helsinki/Finland

Triple Mixed e- / O2- / H+ Conducting (TMC) oxides as oxygen electrodes for H+-SOFC B0414
Alexis Grimaud, Fabrice Mauvy, Jean-Marc Bassat, Sébastien Fourcade, Mathieu Marrony, Jean-Claude Grenier
(1) Université de Bordeaux, CNRS, ICMCB; Pessac Cedex/France
(2) EIFER; Karlsruhe/Germany

Poster Session

Fabrication of cathode supported tubular SOFC through iso-pressing and co-firing route Tarasankar Mahata, Raja Kishora Lenka, Sathi R. Nair, Pankaj Kumar Sinha Bhabha Atomic Research Centre, Energy Conversion Materials Section, Materials Group; Mumbai/India	A0711	**SrMo1-xFexO3-d perovskites anodes for performance solid-oxide fuel cells** R. Martínez, J.A. Alonso, A. Aguadero Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC); Madrid/Spain	B0415
2R -Cell™: A redox anode supported cell for an easy and safe SOFC operation Raphaël Ihringer, Damien Pidoux Fiaxell Sàrl; Lausanne/Switzerland	A0712	**A study on structural, thermal and anodic properties of V0.13Mo0.87O2.935** Berceste Beyribey (1), Çiğdem Timurkutluk (2) (3), Yavuz Ertuğrul (2) , Burcu Çorbacıoğlu (1), Zehra Altın (1) (1) Chemical Engineering Department, Yıldız Technical University; İstanbul/Turkey (2) HYTEM, Nigde University, Mechanical Engineering Department; Nigde/Turkey (3) Vestel Defense Industry, Ankara/Turkey	B0416
Chemistry of Electrodes in Solid Oxide Fuel Cells T. W. Pikea, P. R. Slaterb, K. Kendalla (1) School of Chemical Engineering, b School of Chemistry, University of Birmingham; Birmingham/UK	A0713		
Anode Morphology and Performance of Micro-tubular Solid Oxide Fuel Cells Made by Aqueous Electrophoretic Deposition J. S. Cherng (1)*, W. H. Chen (1), C. C. Wu (1),, T. H. Yeh (2) (1) Mingchi University of Technology, Department of Materials Engineering; Taipei/Taiwan ROC (2) National Taiwan University of Science and Technology, Department of Mechanical Engineering; Taipei/Taiwan ROC	A0714	**Low Temperature Preparation of LSGM Electrolyte-based SOFC by Aerosol Deposition** Jong-Jin Choi, Joon-Hwan Choi, Dong-Soo Park Korea Institute of Materials Science, Functional Ceramics Group; Gyeongnam/South Korea	B0418
		Electrochemical Study of Nano-composite Anode for Low Temperature Solid Oxide Fuel Cells Ghazanfar Abbas, Rizwan Raza, M. Ashraf Ch., Bin Zhuel Department of Physics, COMSATS Institute of Information Technology; Islamabad/Pakistan	B0420
Performance of microtubular solid oxide fuel cells for the design and manufacture of a fifty watts stack. Ana M. Férriz (1), Joaquín Mora (1), Marcos Rupérez (1), Luis Correas (1), Miguel A. Laguna-Bercero (2) Foundation for the development of new hydrogen technologies in Aragon; Huesca/Spain (2) University of Zaragoza, Materials Science Institute in Aragon; Zaragoza/Spain	A0715		
		Electrochemical performance of the perovskite-type Pr0.6Sr0.4Fe1-xCoxO3 Ricardo Pinedo (1), Idoia Ruiz de Larramendi (1), Nagore Ortiz-Vitoriano (1), Jose Ignacio Ruiz de Larramendi (1), T. Rojo (1), (2) (1) Universidad del País Vasco UPV/EHU, Departamento de Química Inorgánica; Bilbao/Spain (2) CIC Energigune, Parque Tecnológico de Álava; Álava/Spain	B0421
Processing of Lanthanum-doped Strontium Titanate Anode Supports in Tubular Solid Oxide Fuel Cells Sean M. Babiniec, Brian P. Gorman, Neal P. Sullivan Colorado School of Mines, Colorado Fuel Cell Center; Illinois/USA-CO	A0716		

Poster Session

Cell and stack design II (Metal Supported Cells) — A09

Recent Developments in Design and Processing of the SOFCRoll Concept — A0907
Mark Cassidy, Aimery Auxemery, Paul Connor, Hermenegildo Viana, John Irvine
University of St Andrews, School of Chemistry; St Andrews/UK

Infiltrated SrTiO3/FeCr-based anodes for metal-supported SOFC — A0908
Peter Blennow, Bhaskar R. Sudireddy, Jimmi Nielsen, Trine Klemensø, Åsa H. Persson, Karl Thydén
Technical University of Denmark, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy; Roskilde/Denmark

Break-down of Losses in High Performing Metal-Supported Solid Oxide Fuel Cells — A0909
Alexander Kromp (2), Jimmi Nielsen (1), Peter Blennow (1), Trine Klemensø (1), André Weber (2)
(1) Technical University of Denmark, Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Division; Roskilde/Denmark
(2) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany

Low Temperature Thin Film Solid Oxide Fuel Cells with Nanocomposite Anodes — A0910
Yuto Takagia (2), Suhare Adam (1), Shriram Ramanathan (1)
(1) Harvard University, Harvard School of Engineering and Applied Sciences; Cambridge/USA-MA
(2) Sony Corporation, Core Device Development Group; Kanagawa/Japan

Quality Assurance Aspects for Metal-Supported Cells — A0911
M. Haydn (1), Th. Franco (1), R. Mücke (2) , M. Rüttinger (1), N.H. Menzler (2), H.P. Buchkremer (2), A. Venskutonis (1), L. S. Sigl (1), M. Sulik (1)
(1) PLANSEE SE, Innovation Services; Reutte/Austria
(2) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research; Jülich/Germany

Effect of Composition Ratio of Ni-YSZ Anode on Distribution of Effective Three-Phase Boundaryand Power Generation Performance — B0422
Masashi Kishimoto, Kosuke Miyawaki, Hiroshi Iwai, Motohiro Saito, Hideo Yoshida
Kyoto University, Department of Aeronautics and Astronautics; Kyoto/JAPAN

Effect of Sr Content Variation on the Performance of La1-xSrxCoO3-δ Thin-film Cathodes Fabricated by Pulsed Laser Deposition — B0423
Jaeyeon Hwang (1), (2), Heon Lee (2) , Hae-Weon Lee (1), Jong-Ho Lee (1), Ji-Won Son (1)
(1) High-Temperature Energy Materials Research Center, Korea Institute of Science and Technology; Seoul/South Korea
(2) Korea University, Department of Materials Science and Engineering, Seoul/Korea

Nanostructure Gd-CeO2 LT-SOFC electrolyte by aqueous tape casting — B0424
Ali Akbari-Fakhrabadi, Mangalaraja Ramalinga Viswanathan
Department of Materials Engineering, University of Concepcion, Concepcion, Chile; Concepcion/Chile

Evaluation of MoNi-CeO2 Cermet as IT-SOFC Anode using ScSZ, SDC and LSGM electrolytes — B0426
María José Escudero (1), Ignacio Gómez de Parada (1), (2), Araceli Fuerte (1), Loreto Dazaa (3)
(1) Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT); Madrid/Spain
(2) Ciudad Universitaria de Cantoblanco, UAM, Madrid/Spain
(3) ICP-CSIC, Campus Cantoblanco; Madrid/Spain

Investigation of the electrochemical stability of Ni-infiltrated porous YSZ anode structures — B0427
Parastoo Keyvanfar, Scott Paulson, Viola Birss
Chemistry Department, Faculty of Science, University of Calgary; Calgary AB/Canada

Poster Session

Cell operation — A10

Multilayer tape cast SOFC – Effect of anode sintering temperature — A1007
Anne Hauch, Karen Brodersen, Christoph Birkl, Peter S. Jørgensen
Risø DTU, Department of Energy Conversion and Storage; Roskilde/Denmark

Sulphur Poisoning of Anode-Supported SOFCs under Reformate Operation — A1008
André Weber (1), Sebastian Dierickx (1), Alexander Kromp (1), Ellen Ivers-Tiffée (1), (2)
(1) Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruher Institut für Technologie (KIT); Karlsruhe/Germany
(2) DFG Center for Functional Nanostructures (CFN), Karlsruher Institut für Technologie (KIT), D-76131 Karlsruhe / Germany

Degradation of a High Performance Cathode by Cr-Poisoning at OCV-Conditions — A1009
Michael Kornely (1), Norbert H. Menzler (3) , André Weber (1), Ellen Ivers-Tiffée (1), (2)
(1) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany
(2) DFG Center for Functional Nanostructures (CFN), Karlsruher Institut für Technologie (KIT), D-76131 Karlsruhe / Germany
(3) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK-1); Jülich / Germany

Evaluation of the chemical and electrochemical effect of biogas main components and impurities on SOFC: first results — A1010
Krzysztof Kanawka (1), (2), Stéphane Hody (1), André Chatroux (3), Hai Ha Mai Thi (4), Loan Phung Le My (4), Nicolas Sergent (4), Pierre Castelli (3), Julie Mougin (3)
(1) GDF SUEZ, Research & Innovation Division, CRIGEN; Saint-Denis la Plaine cedex/France
(2)ECONOVING International Chair in Eco-Innovation, University of Versailles;Guyancourt/France
(3) CEA-Grenoble/LITEN; Grenoble Cedex 9/France
(4) LEPMI, CNRS – Grenoble-INP, Univ. de Savoie – UJF, Saint Martin d'Hères/France

High Electrochemical Performance of Mesoporous NiO-CGO as Anodes for IT-SOFC — B0428
L. Almar (1), B. Colldeforns (1), L. Yedra (2) , S. Estradé (2), F. Peiró (2), T. Andreu (1), A. Morata (1), A. Tarancón (1)
(1) Catalonia Institute for Energy Research (IREC), Department of Advanced Materials for Energy; Barcelona/Spain
(2) University of Barcelona, Department d'Electrònica; Barcelona/Spain

Synthesis of Lanthanum Silicate Oxyapatite by Using Na2SiO3 Waste Solution as Silica Source — B0429
Daniel Ricco Elias, Sabrina L. Lira, Mayara R. S. Paiva, Sonia R. H. Mello-Castanho, Chieko Yamagata
University of São Paulo, Nuclear and Energy Research Institute; São Paulo/Brazil

Prospects and Challenges of the Solution Precursor Plasma Spray Process to Develop Functional Layers for Fuel Cell Applications — B0431
Claudia Christenn, Zeynep Ilhan, Asif Ansar
German Aerospace Center (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany

Tailoring SOFC cathodes conduction properties by Mixed Ln-doped ceria/LSM — B0432
María Balaguer, Cecilia Solís, Laura Navarrete, Vicente B. Vert, José M. Serra
Universidad Politécnica de Valencia, Instituto de Tecnología Química; Valencia/Spain

In-plane and across-plane electrical conductivity of RF-sputtered GDC film — B0433
Sun Woong Kim, Gyeong Man Choi
Pohang University of Science and Technology (POSTECH), Fuel Cell Research Center and Department of Materials Science and Engineering; Pohang/South Korea

High Energy Ball Milling for dense GDC barrier layers — B0434
Mariangela Bellusci, Franco Padella, Stephen J. McPhail
ENEA, C.R. Casaccia; Rome/Italy

Poster Session

Study of Fuel Utilization on Anode Supported Single Chamber Fuel Cell A1011
Damien Rembelski (1), Jean-Paul Viricelle (1), Lionel Combemale (2), Mathilde Rieu (1)
(1) Ecole Nationale Supérieure des Mines de Saint Etienne; Saint Etienne/France
(2) Laboratoire Interdisciplinaire Carnot de Bourgogne; Dijon / France

Anode-supported single-chamber SOFC for energy production from exhaust gases A1012
Pauline Briault (1), Jean-Paul Viricelle (1), Mathilde Rieu (1), Richard Laucournet (2), Bertr, Morel (2)
(1) Ecole Nationale Supérieure des Mines de Saint-Etienne; Saint Etienne/France
(2) CEA-LITEN; Grenoble cedex 9/France

Electrochemical Performance and Carbon-Tolerance of La0.75Sr0.25Cr0.5Mn0.5O3 – Ce0.9Gd0.1O1.95 Composite Anode for Solid Oxide Fuel Cells (SOFCs) A1013
Junghee Kim (1),(2), Ji-Heun Lee (1,3), Dongwook Shin (2), Jong-Heun Lee (3), Hae-Ryoung Kim (1), Jong-Ho Lee (1), Hae-Weon Lee (1), Kyung Joong Yoon (1)
(1) Korea Institute of Science and Technology, High-Temperature Energy Materials Research Center; Seoul/South Korea
(2) Department of Fuel Cells and Hydrogen Technology, Hanyang University, Seoul/South Korea
(3) Department of Materials Science and Engineering, Korea University, Seoul/South Korea

Chromium Poisoning Mechanism of (La0.6Sr0.4)(Co0.2Fe0.8)O3 Cathode A1014
Do-Hyung Cho, Teruhisa Horita, Haruo Kishimoto, Katsuhiko Yamaji, Manuel E. Brito, Mina Nishi, Taro Shimonosono, Fangfang Wang, Harumi Yokokawa
National Institute of Advanced Industrial Science and Technology (AIST); Ibaraki/Japan

Strontium-Doped Nanostructural Lanthanum Manganite B0436
H. Tamaddon (1), A.Maghsoudipour (1)
(1) Ceramics Department, Materials and Energy Research Center; Tehran/Iran

Diagnostic, advanced characterisation and modelling I — B05

3-D Multi-scale Imaging and Modelling of SOFCs B0508
Farid Tariq (1), Paul Shearing (2) , Vladimir Yufit (1), Qiong Cai (1), Khalil Rhazaoui (1), Nigel Brandon (1)
(1) Imperial College London; London/UK
(2) University College London; London(UK

Synthesis and In Situ Studies of Cathodes for Solid Oxide Fuel Cells B0509
Russell Woolley
Imperial College London; London/UK

Quantification of Ni/YSZ-Anode Microstructure Parameters derived from FIB-tomography B0510
Jochen Joos (1), Moses Ender (1), Ingo Rotscholl (1), André Weber (1), Norbert H. Menzler (3), Ellen Ivers-Tiffée (1), (2)
(1) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Jülich/Germany
(2) Karlsruher Institut für Technologie (KIT), DFG Center for Functional Nanostructures (CFN); Karlsruhe/Germany
(3) Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung (IEK-1); Jülich/Germany

Poster Session

Cell testing: challenges and solutions Christian Dosch (1), Mihails Kusnezoff (1), Stefan Megel (1), Wieland Beckert (1), Johannes Steiner (2), Christian Wieprecht (2), Mathias Bode (2) (1) Fraunhofer Institute of Ceramic Technologies and Systems, Winterbergstrasse 28; Dresden/Germany (2) FuelCon AG; Magdeburg-Barleben/Germany	A1015
Diagnostic, advanced characterisation and modelling II	**B10**
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Michael Parkes (1), Greg Offer (1), Nicholas Harrison (2) , Keith Refson (3), Nigel Brandon (1)
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Jamie Sandells, Jamal Uddin, Stephen Decent
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Imperial College London, Department of Materials; London/UK

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Zeynep Ilhan, Asif Ansar
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Anne Morandi (1), Qingxi Fu (1), Mathieu Marrony (1), Jean-Marc Bassat (2), Olivier Joubert (3)
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(3) Institut des Matériaux Jean Rouxel (IMN); Nantes cedex 3 / France

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Yosuke Komatsu (1), Shinji Kimijima (1), Janusz S. Szmyd (2)
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(2) AGH – University of Science and Technology; Krakow/Poland

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Michael Athanasiou (1), (2), Dimitris K. Niakolas (1), Symeon Bebelis (1), (2) , Stylianos G. Neophytides (1)
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Thomas Pfeifer, Markus Barthel, Dorothea Männel, Stefanie Koszyk
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Ludger Blum (1), Robert Deja (1), Roland Peters (1), Jari Pennanen (2), Jari Kiviaho (2), Tuomas Hakala (3)
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Institute of Nuclear Energy Research; Longtan Township/Taiwan ROC

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Kun Zheng, Konrad Swierczek
AGH University of Science and Technology, Department of Hydrogen Energy, Faculty of Energy and Fuels; Kraków/Poland

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(2) Oxiteno S.A.; São Paulo/Brazil

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(2) SOFCpower SpA; Mezzolombardo/Italy

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Universidad del País Vasco/Euskal Herriko Unibertsitatea (UPV/EHU).,Facultad de Ciencia y Tecnología; Leioa (Vizcaya)/Spain

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Chalmers University of Technology, The High Temperature Corrosion Centre; Göteborg/Sweden

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(2) University of Applied Sciences Giessen; Giessen/Germany
(3) Technical University of Dresden (TUD); Dresden/Germany

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Abstracts of all Oral and Poster Contributions

Legend:

- The program includes three **major thematic blocks**:
  1. International Overviews & Development Program (A01, A02), Company & Major groups development status (EU - A04, WW - A05);
  2. Advanced Characterisation, Diagnosis and Modelling (B5, A6, B10);
  3. Technical Sessions on cells, stacks, systems – integration, design, operation as well as interconnects, coatings, seals and material
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  - Poster abstracts are linked to related sessions by letter and first two digits: e.g. A05.., B10, …etc
  - Due to late withdrawals some numbers are missing

A0104

The Status of SOFC Programs in USA - 2012

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Abstract

The development of an electric power generation technology that efficiently and economically utilizes coal – the United States' major domestic energy source - while meeting current and projected environmental and water conservation requirements is of crucial importance to the United States. With that objective, the U.S. Department of Energy (DOE) Office of Fossil Energy (FE), through the National Energy Technology Laboratory (NETL), is leading the research and development of advanced solid oxide fuel cells (SOFC) as a key enabling technology. This work is being done in partnership with private industry, academia, and national laboratories.

The FE Fuel Cell Program, embodied in the Solid State Energy Conversion Alliance (SECA), has three parts: Cost Reduction, Coal-Based Systems, and Core Technology. The Cost Reduction effort is aimed at reducing the manufactured cost of SOFC stacks and associated complete power blocks to $175 per kilowatt and $700 per kilowatt (2007 basis), respectively. The Coal-Based Systems goal is the development of large (>100 MW) integrated gasification fuel cell (IGFC) power systems based upon the aforementioned low-cost fuel cell technology for the production of near-zero-emission electric power from coal. Meeting the latter objective will require a power system that operates with high electric efficiency, captures carbon, and limits to specified levels the emission of other pollutants such as mercury, NOx, and SOx. MW-class SOFC building blocks for central generation plants may see initial commercial market entry in natural gas-distributed generation applications. Program efforts in the Core Technology area involve research and development on rigorously-prioritized technical hurdles, focusing on materials set, processing and design optimization.

Progress and recent developments in the SECA program will be presented.

A0105

Current SOFC Development in China: Challenges and Solutions for SOFC Technologies

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Abstract

Chinese SOFC research and development activities started from end of 1980s. Funding from central government, Ministry of Science and Technology (MOST) has been gradually increased. Currently, more than 30 universities and institutes are involved in SOFC activities. Among them, developments on stacks and systems are carried out in Ningbo Institute of Materials Technology and Engineering (NIMTE), Dalian Institute of Chemical Physics, Shanghai Institute of Ceramics, and Huazhong University of Science and Technology. More research and development activities concerning materials, novel designs, and small stacks are conducted in the universities, for example China University of Mining Beijing, University of Science and Technology of China, Harbin Institute of Technology, etc. There are also companies started to invest SOFC technologies and to become components suppliers. Starting from 2010, MOST has funded one big project targeting 25 kW stacks and 5 kW systems with total budget of 80 million Chinese Yuan. An integrated fundamental research project towards carbon based SOFC system is also funded by MOST with the budget of 34 million Chinese Yuan. In addition to central government funding, financial supports from Chinese Academy of Sciences, Provincial and Municipal Governments are significant. Currently NIMTE is developing 100 kW systems, which is one of the most ambitious goals among the national projects. In this talk, the updated development progresses are introduced and the future commercialization perspectives are indicated. Finally we discuss challenges and solutions for state-of-the-art SOFC technology commercialization, which include comparison of planar and tubular design, anode supported cells and electrolyte supported cells, small stack and large stack module approaches.

A0201

Europe's Fuel Cells and Hydrogen Joint Undertaking

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Abstract

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) was set up to accelerate the development of fuel cells and hydrogen technologies in Europe towards commercialisation from 2015 onwards. To reach this target, the FCH JU brings together resources under a cohesive, public-private partnership. It guarantees commercial focus by matching research, technological development and demonstration (RTD) activities to industry needs and expectations, thereby simultaneously increasing and solidifying links between industry and research communities.

- This unique public-private partnership is composed of the European Union – represented by the European Commission – the European Industry Grouping for a Fuel Cell and Hydrogen Joint Technology Initiative[1] and the New European Research Grouping on Fuel Cells and Hydrogen[2]. The latter two are non-profit associations open to any company and research institute within Europe, EEA and candidate accession countries. All member groups are represented at board level. The *States Representatives Group*, the *Scientific Committee* and the *Stakeholders General Assembly* provide the necessary expert advice. For the period between 2008 and 2013 a predefined budget of nearly €1 billion, contributed jointly by FCH JU members, is foreseen to support research and demonstration projects, and to ultimately accelerate these technologies' market entry.

- Examples of demonstration projects supported by the FCH JU will be presented from its four main application areas: transport and refuelling infrastructure; hydrogen production and distribution; stationary power generation, combined heat and power; and early markets. Some statistics regarding participation in calls for proposals will also be given.

- The state of play on these past and ongoing fuel cell and hydrogen studies in which the FCH JU participates, or which are funded by the FCH JU, will be presented: a portfolio of power-trains for the Europe coalition study, the FCH policy study, the bus coalition study and ongoing activities in individual European member states. Future perspectives of the FCH JU will also be highlighted.

[1] http://www.new-ig.eu
[2] http://www.nerghy.eu

A0202

Commercialization of SOFC micro-CHP in the Japanese market

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Abstract

In recent years micro combined heat and power(mCHP) is gaining attention for its high potential contribution in the residential sector in Japan. We have developed a mCHP based on solid oxide fuel cell(SOFC) technology for both natural gas and liquefied petroleum gas, and have commercialized this in the Japanese market.

This paper introduces the findings we have achieved through the studies prior to commercialization. First, requirements for the Japanese market are analyzed to determine the specification of the SOFC mCHP as a consumer product. Secondly, results from the field tests since year 2007 are analyzed to modify the system, in terms of energy saving and GHG reduction. Laboratory tests of components such as cells stacks and catalysts were also conducted, and the results made it possible for us to guarantee a product life time of 10 years. Finally, the specification and functions of our final commercial products are determined and launched in the market.

Our SOFC mCHP proved the capability to generate approximately 70 % of the electricity consumed in a typical Japanese household of 4 persons. This has an impact of reducing up to 1.3 tons of carbon dioxide emission per year, by installing our SOFC mCHP. Now, reducing manufacturing costs and increasing product value is vital for mCHP to become a sustainable technology in the mass market. Our vision regarding these issues is introduced to conclude the paper.

Basic Function	Power output range	0～700W
	Power generation efficiency	45% (LHV)
	Heat recovery efficiency	42% (LHV)
	Operation mode	24-hour continuous operation (electrical load following)
	Installation	Outdoor

Unit Specification		
Power Generation Unit	Size	900(H)x563(W)x302(D)mm
	Weight	92kg (dryweight)
Hot Water Storage Unit	Tank capacity	90 liters
	Peak boiler	42kW (condensing boiler)
	Size	1,760(H)x740(W)x310(D)mm
	Weight	94kg (184kg at full capacity)

A0203

High Temperature Fuel Cell Activities in Korea

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Abstract

For the past 10 years, South Korea has experienced very dynamic change in the high temperature fuel cell activities. On the government sides, all the public funds to support fuel cell research was centralized with a unified plot plan between 2003 ~ 2009. It resulted in heavy focus molten carbonate fuel cells (MCFC) for a larger scale power plant, but the results were dissatisfied despite almost 50% budget was allocated in this area. This was mostly because all the companies adopt external type, which is good at using variety of fuels but bad at scaling up to larger MW scale. POSCO was brave enough to abandon further development of the external type, and decided to import the internal reforming type from FCE in 2007. With an investment of USD 600M, they now have the world largest fuel cell manufacturing plant in Pohang city with 100MW stack manufacturing plant and 50MW BOP assembly plant. In 4 years from 2008, they succeeded in installing 46MW of MCFC power plants throughout Korea, and all the manufacturing technologies of FCE stacks will be transferred to POSCO by the end of this year. POSCO energy also developed 100KW MCFC system for building, and are under test now in Seoul city.
Active involvement of various companies for SOFC research has a rather slow start after the budget centralization was deregulated in 2009. Research includes developing various kinds SOFC stacks of planar, tubular and flat tube type and developing BOPs and parts by variety of funds such as development fund from KETEP (Korea energy technology evaluation and planning) of MKE (ministry and knowledge and economy), basic research fund from NRF (national research foundation) of MES (ministry of education and science), regional project of DGLIO and HFCTB project for fuel cell test-bed from MKE and providential governments. Here introduced are major SOFC research activities and their development status.

A0401

SOFC System Development at AVL

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Abstract

AVL is involved in SOFC system development since 2002. At the moment 2 major system development programs are under way with various partners. The aims of the 2 programs are: to develop a mobile diesel fuelled SOFC Auxiliary Power Unit (APU) and an 8kW modular stationary power generator fuelled with natural gas.

The mobile SOFC APU Gen I is available in hardware since end of 2011. The APU is designed for 3kW net electric power at a target efficiency of 35%. The weight of the complete system is 70kg and the volume around 90L. The main features of the system are: a hot-gas anode recirculation loop, highly efficient radial blowers and a very integrated system design. The stack is an anode supported type from TOFC in a very robust housing for this application. The blowers have been developed within AVL and enable operation till 500°C gas temperature (for anode recirculation) as well as net electric compression efficiencies above 50%. The system, including all major features and first operating experience, will be shown and discussed. Additionally the AVL LOAD MATRIX process, which is used for systematic durability and reliability development of the AVL SOFC APU, will be presented.

The stationary system is developed within the project SOFC20 with following partners: Plansee, IKTS, FZJ and Schott. AVL is responsible for the complete system development. IKTS and Plansee supply the stacks as well as the stack module assembly. The system has a hot gas anode recirculation loop to maximize the efficiency. The efficiency target is above 50%. The system is operated with natural gas. To maximize the efficiency, steam reforming at rather low temperatures has been selected to take additional advantage of stack internal reforming. As for the mobile APU, AVL also develops radial blowers for the stationary system with similar targets: hot gas operation till 600°C and very high efficiencies. Due to the lifetime expectation of stationary systems a completely different bearing approach has been chosen for the stationary blowers. In the meantime the complete system has been built up. The stack module has been delivered and installed. First tests with the system have been performed.

A0402

Status of the Solid Oxide Fuel Cell Development at Topsoe Fuel cell A/S and Risø DTU

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Abstract

Many years of collaboration between DTU Energy Conversion (formerly Risø DTU) and Topsoe Fuel Cell A/S (TOFC) on SOFC development has ensured an efficient and focussed development programme including transfer of up-front knowledge to applied technology. Expansion and strengthening of the world-wide collaboration network contribute to a continuous development and improvement of the SOFC technology. TOFC provides the SOFC technology platform: Cells, stacks, and integrated stack module for different applications focussing on cost effectiveness, reliability and durability under real operation conditions. The SOFC development in the consortium of TOFC and DTU Energy conversion includes material development and manufacturing of materials, cells and stacks based on state of the art as well as innovative strategies. A significant effort is directed towards improvement of current generations as well as development of the next generation SOFC technology. The innovative concept of the next generation, aiming at improved reliability and robustness, is based on metal-supported cells and nano-structured electrodes with perspectives of several potential advantages over conventional Ni-YSZ anode supported cells. Recently, record-breaking results have been obtained on cell level as well as on stack level. The collaboration has the objective to effectively transfer scientific results to industrial technology up-scaling and application. Within the anode supported cell and stack technology TOFC is engaged in development and demonstration of stack assemblies, multi-stack modules and PowerCore units that integrate stack modules with hot fuel processing units. TOFC collaborates with integrator partners to develop, test and demonstrate SOFC applications.

A0403

Progress in the Development of the Hexis' SOFC Stack and the Galileo 1000 N Micro-CHP System

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Abstract

Hexis is a developer and manufacturer of the SOFC-based Micro-CHP system Galileo 1000 N. More than 100 Galileo 1000 N systems have been installed up to now and are in operation at customer's sites and in the lab. This contribution will focus on the newest achievements mainly in the lab on the efficiency, the durability and cyclability of SOFC stacks and complete micro-CHP systems.
Regarding the efficiency, tests on the new generation of the Galileo 1000 N achieved a total efficiency of 95 % (LHV) in fuel cell operation mode and an electrical efficiency of 34 % (AC, net, LHV) with the use of Hexis' standard CPOx reformer. On 5-cell stack level, electrical efficiencies of up to 44 % (DC) were achieved with CPOx reforming and 55 % (DC) with steam reforming.
Looking at durability, a long-term system test that was started in 2007 has now achieved more than 40 000 hours of operation with a power degradation rate of approx. 1.6 % per 1000 h in the first 36 000 h and no progressive degradation. Newer tests include a system test over more than 4500 h and a power degradation of approx. 0.5 % per 1000 h. On 5-cell stack level, a voltage degradation of approx. 0.4 % per 1000 h was measured over 4000 h.
The cyclability was significantly improved in the last year. On 5-cell stack level, 57 full redox cycles (complete anode re-oxidation) were carried out. The first 40 cycles resulted in no significant degradation of the fuel cell stack and also in no significantly increased long-term degradation after these cycles.
With the current status, Hexis' stack technology is considered ready for the planned market introduction in 2013. Nevertheless, some of the tests have to continue for longer times and statistical certainty has to be increased by increasing the number of tests and testing the stacks in the real life environment of a field test, which is currently in implementation.

A0404

Development and Manufacturing of SOFC-based products at SOFCpower SpA

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Abstract

SOFCpower SPA provides efficient energy solutions based on its proprietary planar SOFC technology. Company focus are products that use natural gas either for heat and power generation (CHP) or for distributed power generation at high total and electrical efficiencies, respectively. In this respect, the company develops and manufactures SOFC power modules in close collaboration with European heat appliance OEMs and utilities. Furthermore, the company is evaluating strategic technology options for planar electroceramic membrane reactors, *e.g.* the use of its SOFC stack technology for high temperature electrolysers (SOE). In this field, HTceramix leads the European FCH-JU project ADEL (ADvanced ELectrolysers).
With several years of operational experience in running its pilot plant in Italy (Mezzolombardo, TN), SOFCpower has consolidated its manufacturing knowhow and capabilities and has confirmed the competitiveness of its products, which are capable to match target market requirements and being produced at less than 1,000 €/kW_e.
Collaboration with Industrial component suppliers and integrators has largely increased in intensity, this approach being considered as a key success factor to reach the cost and reliability targets required from the stationary market. First unit(s) are operating as sheltered field tests in the Trento region and will be enlarged with the participation in the incoming ENE.FIELD trials.
The paper provides an update of the stack and system development, including operational results of SOFC-based mCHP and stacks operated in electrolysis mode.

A0405

Recent Results in JÜLICH SOFC Technology Development

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Abstract

Forschungszentrum Jülich has been working on the development and optimization of solid oxide fuel cells (SOFC) based on a planar anode supported design for almost 20 years. The SOFC group at JÜLICH has up to now assembled and tested more than 450 SOFC stacks with power outputs between 100 W and 15 kW. The research and development topics cover many areas ranging from materials development over manufacturing of cells, stack design, system components, mechanical and electrochemical characterization, to system design and demonstration, always supported by feedback from post-test characterization.
Within the framework of the cell development, optimized anode supported cells (ASC) with two different cathode materials have been standardized. Three different manufacturing routes have been established: one “classical” route based on laboratory-scale technologies, a second route which allows technological scale-up and a third novel route which drastically reduces the manufacturing and sintering steps and thus minimizes costs. JÜLICH has established anode-supported cells with a power density of more than 4 A cm^{-2} (extrapolated) at 800 °C and 0.7 V with hydrogen/air in a single cell environment.
The use of improved steels, cathodes, contact and protective layers as well as optimized materials processing have resulted in a significant reduction of the voltage degradation rate to about 0.15% per 1 000 hours at 700 °C under a current load of 500 mA cm^{-2}. This is, in fact, currently demonstrated in an ongoing test for a short stack with improved protective coating on the metallic interconnects, which has reached more than 11,000 hours of operation. This may indicate a breakthrough in durability for planar SOFC technology. In addition, the benchmark stack of the Real-SOFC project, which test started in August 2007, has concluded 40,000 hours at the beginning of March 2012, and is still in operation.
This operation behavior has to be verified for larger stacks, composed of cells with a size of 20 x 20 cm^2. This development is strongly supported by modeling and material and design optimization with respect to improved flow geometries and reduced internal thermo-mechanical stress to ensure long-term gas tight operation. The first two 5 kW stacks have been successfully pre-tested and will be integrated into the 20 kW system already been completed.

A0406

Compact and highly efficient SOFC Systems for off-grid power solutions

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Abstract

SOFC, especially planar type technology, today is worldwide in the focus for residential and stationary power applications with electric powers of 1 kW up to megawatt scale systems. However smaller systems applying liquid hydrocarbon fuels can be an interesting alternative to conventional generators or PEM type fuel cell systems in the power range of up to 1000 W, because of their simplicity, high efficiency, robustness and thus reliability and cost efficiency.
The company new enerday GmbH develops and produces very compact and highly efficient SOFC systems for off-grid power solutions in the power range of up to 1 kW electric. With 10 years' experience from the former SOFC development program at Webasto, the team at new enerday continued with a focused product development in the new company founded in 2010.

After market analysis and discussions with market partners in the field of off-grid power and leisure systems, new enerday decided to focus on the power range of 500 – 1000 W electric. Fuel for market entry will be the worldwide available logistic fuel LPG. Market potentials for this fuel are obviously limited, e.g. in the field of marine and motor home leisure application. However developments for other fuels like ethanol and diesel SOFC systems are running at new enerday, because of the potential for real volume markets.

Promising markets applications for SOFC off-grid power solutions are e.g. medium sized sailing and motor yachts. The need for a quiet, reliable and powerful battery charger in this less price sensitive premium market is extremely high. Running out of batteries is annoying reality after some hours sailing without recharging by motor generator or regularly shore power availability.

Latest development results at new enerday for a very compact, highly efficient and close to series 500 W LPG system for different markets will be presented. Special emphasis will be put on efficiency and duration test results for LPG of field quality.

A0407

Overview of status in the EU and European Hydrogen and Fuel Cell Projects

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Abstract: HyFACTS, FC-HyGUIDE, HyProfessionals

The presentation would include general overviews of 3 European funded projects that deal with Fuel Cell and Hydrogen (FCH) technologies. The opportunity may be taken by EHA to also present the current status of the European Policy scenarios. As clean energy and transport are key in Europe 2020 targets, FCH are now playing an increasingly important role in Europe, EHA as a representative of 20 National Associations monitors these developments while communicating to policy makers and institutions on the impact of FCH.
HyFACTS: Identification, Preparation and Dissemination of Hydrogen Safety Facts to Regulators and Public Safety Officials- An increasing number of upcoming installations of hydrogen-related technologies are foreseen in public areas. The HyFACTS is a European project funded with 1 M€, lasting 2,5 Years, the project aims to develop and disseminate fully up-to-date material in the form of customized training packages for regulators and public safety experts providing accurate information on the safe and environmentally friendly use of hydrogen as an energy carrier for stationary and transport applications under real conditions.
FC-HyGuide: Life Cycle Assessment (LCA) Guidance for FCH Technologies. The overall objective of FC-HyGuide is to develop a guidance document, related training materials and courses for LCA studies on fuel cells and hydrogen production. Based on the ILCD Handbook procedure and together with specific examples this manual offers step by step guidance for LCA practitioners in industry as well as for researchers. The Document is currently under review by the European Commission; however at the date of the 10th EUROPEAN SOFC FORUM public distribution of the document will be possible. The document examines SOFC and PEM FCs.
HyProfessionals: Development of educational programmes and training initiatives related to hydrogen technologies and fuel cells in Europe. Today's technicians and students are the next generation of potential fuel cell users and designers. Educating future professionals is a critical step as electric transport and infrastructure are developed in Europe; specialists in hydrogen infrastructure installations will be needed to fulfill future demand in human capital within these innovative technologies. The HyPROFESSIONALS project funded by the European Fuel Cell and Hydrogen Joint Undertaking is focused on the development of educational programmes and training initiatives for technical professionals to secure the required mid- and long-term availability of human resources capable to properly operate hydrogen fuel cell technologies safely.

A0501

Latest Update on Delphi's Solid Oxide Fuel Cell Stack for Transportation and Stationary Applications

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Abstract

Delphi is developing Solid Oxide Fuel Cell (SOFC) technology for applications in a variety of markets, in participation with the U.S. Department of Energy (SECA, EERE). This paper outlines the development of SOFC stacks and discusses the latest results, including key features of the cell and stack developed under the SECA program, Delphi's progress in demonstrating the technology as an Auxiliary Power Unit for trucks and stationary applications, and key achievements toward meeting goals for commercialization.

A0502

Solid Oxide Fuel Cell Development at Versa Power Systems

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Abstract

Versa Power Systems (VPS) is a developer of solid oxide fuel cells (SOFCs) for clean power generation. The commercialization of SOFCs requires the development of enabling cell and stack technology combined with an engineering focus on manufacturability and cost reduction. Cell and stack development at VPS has focused on low-cost intermediate temperature planar anode-supported SOFC technology. In order to ensure the emergence of cost-competitive solutions, the development effort has emphasized the use of conventional materials (such as YSZ, nickel, ferritic stainless steel) and volume manufacturing processes (tape casting, screen printing, continuous co-firing). This has resulted in a mechanically and electrochemically robust stack design. This paper will present recent development highlights regarding VPS' SOFC cell and stack technology.

A0503

BlueGen for Europe – Commercialisation of Ceramic Fuel Cells' residential SOFC Product

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Abstract

With 20 years SOFC experience and 6 years field testing experience (about 900000 operating hours with four field system generations), Ceramic Fuel Cells (CFCL) has developed a 2kW residential generator product, fully optimizing the prime advantages of SOFC technology – very high electrical efficiency and load modulation over a wide range with high efficiency. Bluegen, a modular electricity generator with heat recovery is based on CFCL's fuel cell module Gennex, consisting of a 51 layer stack with 204 anode supported cells in a 2x2 window-frame design, the heat management system (heat exchanger and start-afterburner), the pre-reformer and steam generator. Gennex is a "methane" fuel cell module (direct internal reforming of methane – the "chemical combined cycle") with a DC efficiency of around 68%. The fuel cell appliance BlueGen has a peak NET AC efficiency of 60% at 1.5kW output, and can be power modulated between 500W and 2kW with electric efficiencies between 40 and 60%. The combined thermal efficiency of the 2011 model is up to 85%.

BlueGen obtained CE product certification in April 2010, and has been installed in 9 countries worldwide, but with primary focus on the European market, in particular Germany, The Netherlands and UK. The combined fleet of over 150 Bluegen and integrated systems installed to date has clocked up about 700000 operating hours. The earliest BlueGen installations have been running for over 13000 hours. There are some degradation variations between systems, but many systems show an efficiency degradation of about 1%/1000hrs after about 4000hrs operation.

BlueGen is the first commercially available SOFC system in Europe through its distribution partners [1] and service providers who sell, install and maintain the systems. An internet platform bluegen.net provides BlueGen performance data and control functionality to customers and service companies.

In January/February 2011, the manufacturing capacity in its Heinsberg facility has been extended from stack assembly to BlueGen assembly, with a current capacity of 1000 Bluegen systems per year, but readily extendable to 2500 system per year. In addition, Bruns Heiztechnik, BDR and Ideal Boilers produce integrated fuel cell heating systems (fuel cell + condensing boiler) in Germany, France and United Kingdom.

A0504

SOFC system integration activities in NIMTE

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Abstract

The fast depletion of fossil fuel resources and the environmental pollution are the major issues caused by the abundant use of fossil fuels. These issues have led to the exploration of alternative energy conversion systems. Solid Oxide Fuel Cell (SOFC) system has the advantages such as low to zero emissions during operation, flexibility of operation and ease of integration with other systems. Therefore, developing and commercializing a SOFC system attracts much interest.
In China, the biggest SOFC program currently is run by Ningbo Institute of Materials Technology and Engineering (NIMTE), Chinese Academy of Sciences (CAS). In this paper, current status of SOFC system integration in NIMTE is summarized. To accomplish the integration of SOFC system, various BOP components have been developed and manufactured including porous media combustor, reformer, vaporizer, heat exchanger and power electronics. Many efforts have been done to increase the system's performance. The water to methane ratio is an important parameter that affects the reformer's performance. By modifying the vaporizer's structure and controlling its overall heat transfer coefficient, we successfully stabilized the steam supply. A compact methane reformer powered by porous media burner was also manufactured and its performance was investigated. This reformer contains an annulated column metal monolith catalyst in which a porous media is placed inside. Natural gas is burned in the porous media to power the steam reforming of methane that reacts in the metal monolith catalyst. In the annulated column metal monolith catalyst, active component Ni was coated on the metal surface which was used to catalyse the steam reforming reaction. A series of experiments was carried out and results showed that this reformer can work stably and effectively to provide hydrogen for the SOFC system.
With our mass-produced anode-supported SOFC stacks, we have developed a 1kw class and a 5kw class SOFC system for stationary power generation. Both 2 systems use nature gas as fuel. And the calculated power generation efficiency is about 40%. Optimization and a thermally self-sustaining system are still undergoing by improving the structure of heat zone and control strategy. Our target is integrating a 100KW system in the next 5 years.

A0505

Development of SOFC Technology at INER

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Abstract

The Institute of Nuclear Energy Research has committed to developing the SOFC technology since 2003. Through elaborate works for years, substantial progresses have been made on cell, stack, BOP components as well as system integration. Fabrication processes for planar anode-supported-cell (ASC) by conventional methods and metal-supported-cell (MSC) by atmospheric plasma spraying are well established. ASC cells with various compositions of electrodes and electrolytes are investigated for different applications. At this stage, the maximum power densities of INER's ASCs are 652 mW/cm^2 at 800 ^{o}C for IT-SOFC (600~800 ^{o}C) and 608 mW/cm^2 at 650 ^{o}C for LT-SOFC (400~650 ^{o}C). The power densities of INER's MSCs are 540 mW/cm^2 and 473 mW/cm^2 at 0.7 V and 700 ^{o}C for a cell and a stack tests, respectively. Durability test for MSCs at constant current densities of 300 mA/cm^2 and 400 mA/cm^2 indicates the degradation rate is less than 1%/khr. Procedures and techniques for stacking and cell/stack performance tests are continuously improved to enhance the quality and reliability. Comparable or higher power performance is now achieved with respect to the specs of commercial cells at similar operating conditions. Consistent performance within a variation of 2% is obtained for 3 modules of 18-cell stacks at a nominal power output of 500 W. Meanwhile, INER's MSC 18-cell stack has brought a power output higher than 500 W as well.
Innovative nano-structured catalysts, in which reduced Pt and CeO_2 particles dispersed onto the Al_2O_3 carriers can effectively prevent the migration and coalescence of the metal crystallites, are thermal stable and possess a conversion ratio higher than 95% for reforming of natural gas. A non-premixed after-burner/reformer is designed and fabricated, and it has passed the prerequisite functional tests. Layouts including stacks, components of BOP, power conditioning and control as well as gases and water supply, are designated for a 1-kW SOFC power system. In compliance with system requirements, operating modes, data acquisition, power conditioning, instrumentations, and control logics have been identified and settled. A series of system validation tests are carried out to check functions and interfaces of components and to resolve potential problems for a power system. After successive system validation tests, two modules of 18-cell stacks are allocated into the SOFC system. Test results indicate a thermal self-sustaining system on natural gas is achieved with a power output of around 760 watts.

A0506

Techno-economical analysis of systems converting CO_2 and H_2O into liquid fuels including high-temperature steam electrolysis

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Abstract

The feasibility of hydrogen production via reverse SOFC operation (SOEC) has been demonstrated in many tests. It has also been proven that degradation in SOEC-mode can be minimized by lower impurity contents and adapted power densities. [1]

Future large scale hydrogen production will merely not be an isolated, singular process. It will rather be integrated into chemical process plants that can provide steam from waste heat and use hydrogen for further conversion and synthesis processes. Therefore it is important to not only optimize SOEC towards internal parameters but to also consider the requirements from the connected processes.

Sunfire is developing a process to produce fuels from CO_2 and H_2O containing a SOEC as its core component. The three main process steps are (1) SOEC (2) CO_2-conversion to produce syngas and (3) fuel synthesis. The technical characteristics represented by this process are similar to a variety of future petro- and chemical production processes using renewable hydrogen.

This paper shall contribute to estimating the relevance of various SOEC operation parameters.

The most important ones are SOEC efficiency and SOEC pressure level which is ideally defined by the temperature of the cooling agent of the subsequent synthesis. As SOEC is an endothermic process, the feed-in of thermal energy via hot steam can lower the amount of required electric energy.

Overall system efficiency is mainly determined by heat losses as long as endothermal operation can be ensured.

This paper will give an overview of the different SOEC operation parameters and their economic impact on overall integrated processes using SOEC.

A0507

Approach to Industrial SOFC Production in Russia

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Abstract

At present time, the problem of SOFC production with a power up to 10 kW for industrial and domestic use becomes more and more important in Russia. Though research and development in this field was started rather long ago and was rather successful in Russia a gap between science and industrial production was still rather large. Several Federal projects supported by the Ministry of Education and Science of RF created a good background for further steps to the industry but such steps were not done due to some technical and economical problems. To overcome these problems cooperation of the leading research centers and the industry was necessary. Last year the program of Fuel Corporation - Joint Stock Company "TVEL" on SOFC was started. Main participants are Enterprises of "TVEL", NRC "Kurchatov Institute", Institutes of Russian Academy of Sciences and some private and public Enterprises. It is necessary to underline that among TVEL Enterprises are Joint Stock Company Ural Electrochemial Combine the most successful industrial enterprise which is producing fuel cells and accumulators for space industry and Joint Stock Company "Chepetsky Mechanical Plant" – the largest producer of zirconium dioxide ceramics in Russia. The main potential users are Public Corporation "Gasprom", renewable energy and aircraft industry. In the first case the demand for SOFC for cathode pipes protection and monitoring stations exists for a long time but up to now it is not satisfied though the price level in this case may be a little bit higher then for other industrial application fields due to absence of centralized electric greed in many regions of gas transportation and high price of alternative electric energy sources.
Tubular design of SOFC was rather well developed and a 1,5 kW pilot plant was build but tests in real environment with customer's equipment were not done up to now. At present time only tests of 0,1 kW SOFC pilot plant with external converter are carrier out at one of "Gasprom" subsidiary production unit. Next stages are 3 kW SOFC (tubular design) power plant production and tests at "Gasprom" enterprises and 0,5 kW (planar design) production and tests. In parallel a model shop for SOFC power Plants production is build. Among the main R&D goals are total exclusion of platinum metal use and development of stainless steel current collectors and bipolar plates. A lot of attention is paid to the stack design and some new possibilities such as cone shape cells are under the tests. As a necessary component of successful production development, a semi-industrial polygon for tests and demonstration is under development.
For such a program, external suppliers and collaborators are taken into account.

A0601

Studies of Solid Oxide Fuel Cell Electrode Evolution Using 3D Tomography

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Abstract

This paper describes 3D tomographic investigations of structural evolution of solid oxide fuel cell (SOFC) Ni-YSZ and LSM-YSZ composite electrodes. The aim is to determine the fundamental limits on the electrode durability in the absence of impurities. This talk will focus on temperature effects without electrode current. Temperatures higher than normally used in SOFC operation are utilized to accelerate electrode degradation. The ability to extrapolate such data to predict long-term durability requires accurate mechanistic models of degradation mechanisms. Information from quantitative 3D imaging is used as a tool for developing such models.

3D FIB-SEM results are presented showing structural changes in Ni-YSZ anode active layers upon extended annealing in humidified hydrogen at 900 – 1100°C. A limited amount of Ni coarsening was observed, leading to a decrease in three-phase boundary density. However, the main effect was that a large fraction of pores became isolated, leading to a substantial decrease in active TPB density that explained the observed increase in polarization resistance.

Structural and electrochemical changes in LSM-YSZ electrodes under similar accelerated aging conditions will also be discussed. In this case, the polarization resistance of optimally-fired electrodes increased upon aging, whereas that of under-fired electrodes improved upon aging. These results are explained in terms of the observed microstructural changes.

A0602

Electrochemical Impedance Spectroscopy: A Key Tool for SOFC Development

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Abstract

Electrochemical impedance spectroscopy (EIS) has been established over many years as a powerful measurement technique for the electrical characterization of electrochemical systems. EIS is especially useful if the electrochemical system performance is governed by a number of coupled processes each proceeding at a different rate. Fuel cells are prominent examples of complex dynamic materials systems, as its physical processes span over a wide range of frequencies. The physical interpretation of these kinetic information is the key to predicting fuel cell properties under different operating conditions and different materials configurations and thus to enable a well-directed improvement of fuel cell performance. However, the relaxation times of the physical processes themselves cannot be observed directly from the measurement data if their impedance contributions overlap in the spectrum. Therefore, the impedance data has to be analyzed with respect to the underlying dynamic processes.
Commonly, the recorded impedance spectra are analyzed by a complex nonlinear least squares (CNLS) fit to an *a priori* defined equivalent circuit model (ECM). However, this approach contains different well known weaknesses, which can be summarised as follows: (i) poor resolution in the frequency domain, (ii) an *a priori* defined electrical equivalent circuit is needed, (iii) ambiguity of the proposed equivalent circuit.
Nevertheless, in recent years the so called distribution of relaxation times (DRT) method has proven to be a valuable approach to the challenge of finding an adequate ECM able to describe the physical behaviour of SOFC single cells. In this contribution special emphasis is put on the course of impedance measurement and analysis. Specific issues will be: (i) data quality, (ii) design of an appropriate measurement program, (iii) development of an ECM and identification of optimal starting parameters for the CNLS algorithm, (iv) validation of the developed ECM by impedance analysis at convenient operating conditions.

A0603

In-operando Raman spectroscopy of carbon deposition from Carbon Monoxide and Syngas on SOFC nickel anodes

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Abstract

Advances in solid oxide fuel cell (SOFC) and solid oxide electrolyzer (SOEC) technology are dependent upon improvements in durability, efficiency and cost. However, in order to improve durability it is necessary to understand degradation modes and failure modes in greater detail, in particular to understand them at a fundamental level. In-situ Raman Spectroscopy is emerging as a key tool in the development of a fundamental understanding of many of the kinetic processes occurring during SOFC operation.

We report the development of a new miniaturized SOFC test rig with optical access enabling the use of in-situ Raman spectroscopy to probe processes occurring at the electrodes under normal operating conditions, effectively in-operando. This design combines the advantages of previously reported designs, namely (i) integrated fitting for mounting on a mapping stage enabling 2-D spatial characterisation of the surface, (ii) a compact profile that is externally cooled, enabling operation on an existing microscope without the need for specialized lenses, (iii) fully controllable dual atmosphere operation enabling fuel cell pellets to be tested *in operando* with either electrode in any atmosphere being the focus of study, (iv) combined electrochemical measurements with optical spectroscopy measurements with the potential for highly detailed study of electrochemical processes, (v) the ability to cool very rapidly, from 600°C to 300°C in less than 5 minutes without damaging pellets or the experimental apparatus, and (vi) the ability to accommodate a range of pellet sizes and thicknesses.

We also report results of investigations into carbon formation kinetics during operation of a nickel anode at intermediate temperatures (600°C) in pure dry CO and simulated syngas (CO & H_2) mixtures. Results indicate that carbon formation kinetics from the Boudouard or CO disproportionation reaction are relatively slow, and that the presence of hydrogen significantly accelerates the rate of carbon formation. The type and speed of carbon formation is also different depending on whether the cell is being held at OCP or at moderate currents (100mA cm^{-2}), and in both cases is higher in the presence of hydrogen. The results are relevant to SOFCs operating on syngas, and to SOECs being used for co-electrolysis of H_2O and CO_2 at high utilizations.

A0701

Co-sintering of Solid Oxide Fuel Cells made by Aqueous Tape Casting

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Abstract

Solid Oxide Fuel Cells (SOFC) are typically produced using organic solvent tape casting of one layer (electrolyte, anode or cathode) followed by deposition of the other layers by complex methods such as physical vapour deposition. Our aim is instead to use aqueous tape casting, followed by co-sintering. These are less costly processes, which causes less CO_2-emissions, but co-sintering is a critical step. Both shrinkage and thermal expansion must be matched, and of course also the sintering temperature.

Using water-based tape casting we have demonstrated co-sintering of NiO/YSZ-anode with 30% porosity and dense YSZ-electrolyte, in planar and tubular shapes. We have also shown that tape casting is a suitable prototype method for tubes. On-going work aims at increasing the porosity and decreasing the working temperature of the cell.

A0702

Powder Injection Molding of Structured Anode-supported Solid Oxide Fuel Cell

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Abstract

Power Injection Molding (PIM) gives the possibility to produce at an industrial rate ceramic parts with fine details. It is thus a possible approach to reduce the fabrication costs of Solid Oxide Fuel Cells (SOFC). This work presents fabrication and electrochemical characterization results of injection-molded structured anode-supported SOFCs.

Planar anode-supported SOFC with fine details have been produced by injection molding of nickel oxide (NiO) and yttria-stabilized zirconia (YSZ). The channeling structure and support porositiy ensure gas transport on the fuel side. After YSZ electrolyte deposition using spin coating, a half cell is co-sintered. Electrochemical testing is carried out with a lanthanum-strontium manganite (LSM)-YSZ cathode. The performance is comparable to tape cast anode-supported cells, with 0.45 W cm^{-2} at 0.6 V and 810°C. Medium term galvanostatic testing shows a degradation rate of about 1.1% / kh. Electrochemical impedance spectroscopy (EIS) and energy dispersive X-ray spectroscopy (EDS) analyses attribute this to cathode degradation due to Cr and S poisoning.

This paper is to our knowledge the first published electrochemical test of a planar structured anode-supported SOFC produced via a powder injection molding (PIM) process. The results are promising for using a PIM fabrication process in the SOFC field.

A0703

Inkjet Printing of Segmented-in-Series Solid-Oxide Fuel Cell Architectures

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Abstract

The segmented-in-series (SIS) solid-oxide fuel cell (SOFC) architecture enables high-voltage and low-current power generation on a single substrate, and is actively under development by a number of industrial and academic groups. Low-cost, readily accessible screen-printing technology is commonly utilized for SIS-device fabrication, limiting feature size to approximately 100 µm. In this report, we describe our application of a high-precision inkjet-printing technology for fabrication of SIS SOFC devices. Through the use of inkjet deposition, SOFCs on the scale of tens-of-microns may be printed and connected in electrical series to produce high-voltage, low-current devices.

In this work, a Fuji Dimatix DMP 2831 inkjet printer is utilized to deposit SOFC materials onto a porous 3 mole-% yttria partially stabilized zirconia (PSZ) substrate. The anode, electrolyte, and cathode materials are comprised of Ni, YSZ, and LSM, respectively. Lanthanum-doped strontium titanate ($Sr_{0.8}La_{0.2}TiO_3$) is utilized as the interconnect material. Ceramic powders are processed into colloidal inks to meet the viscosity and surface-tension requirements of the inkjet printer. Inks are formulated to minimize agglomeration and to prevent clogging of the inkjet nozzles.

In this report, colloidal-ink development, printing-parameter optimization, and deposit morphological characteristics of the inkjet-printed segmented-in-series devices are presented.

A0704

Miniaturized free-standing SOFC membranes on silicon chips

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Abstract

Due to their high specific energy and high energy density, miniaturized low-temperature (350-550°C) solid oxide fuel cells, hereafter abbreviated “micro-SOFC”, are believed to constitute one of the technologies that could help satisfy the continuously increasing electric energy demand for mobile devices such as laptops and camcorders. Using thin film and MEMS technologies, cathode-electrolyte-anode layer assemblies as thin as 1 µm are deposited on silicon substrates that are micromachined to form arrays of free-standing membranes (surface area: 390x390 μm^2 at ETH Zurich). Proof of concept was already established by several groups and high power densities of several hundreds of mW/cm^2 have been reported at temperatures as low as 350 °C.

In Switzerland, the OneBat® consortium consisting of eight research groups is working on the development of the micro-SOFC technology covering various aspects such as membrane fabrication and characterization, reformer catalysis, thermal management and system development. After a brief presentation of the consortium activities as well as the state-of-the-art of the micro-SOFC research worldwide, this contribution will lay emphasis on the core of the micro-SOFC technology, namely the electrochemical cells, and address key-aspects for their further development:

- fabrication and thermomechanical stability of free-standing membranes
- development of cost-effective thin film deposition techniques
- development of thermally stable electrodes

A0705

Large-area micro SOFC based on a silicon supporting grid

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Abstract

Recent advances on the development of micro solid oxide fuel cells (SOFCs) show the suitability of working as energy suppliers for portable applications (low power regime of about 1-5W). Until now, most of the works has been focused on the fabrication of micro SOFCs based on free-standing thin electrolyte membranes, supported on different substrates [1]. In this sense, the authors have recently published the fabrication of YSZ free-standing membranes supported on silicon-based micro-platforms to be used as electrolytes in a micro SOFC, obtaining high mechanical stability and good electrical properties at temperatures as low as 450-550ºC [2].
However, limitations on the maximum power achievable with those membranes appeared, related with the relatively low size of the membranes. Although an aspect-ratio of 10-7 cm-1 is already available, i.e. 200nm thick YSZ membranes with an area of 500x500µm2, the development of larger areas of membrane is primal to improve the total power of a single micro fuel cell. Only a few works have been focused on this issue, consisting on the fabrication of larger YSZ free-standing membranes supported by dense metallic arrays [3]. These arrays are placed at one side of the membrane and can act as current collectors too. Here we present a different approach, based on the use of the silicon technology to fabricate larger membranes supported on an array of doped silicon nerves. Thus, large area free-standing YSZ membranes have been fabricated over those silicon nerves.

A0706

Fabrication and Performance of $Nd_{1.95}NiO_{4+\delta}$ (NNO) Cathode supported Microtubular Solid Oxide Fuel Cells

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Abstract

Microtubular SOFC present significant advantages in comparison with the traditional planar SOFC configuration. In particular, the tubular design facilitates sealing and also reduces thermal gradients. As a consequence, rapid starts up times are possible. In addition, another advantage of the microtubular configuration is their higher power density per unit volume. Due to these properties, those devices are especially attractive for portable applications.

There has been a great interest in microtubular SOFCs in the recent years, mainly using anode supported cells. Electrolyte supported cells have also been reported, but there are relatively few investigations using the cathode as the support.
In the present paper, $Nd_{1.95}NiO_{4+\delta}$ (NNO) has been chosen as the cathode support, as it presents superior oxygen transport properties in comparison with other commonly used cathode materials, such as LSCF or LSM, and these material has been proven as an excellent cathode for SOFC and SOEC applications.

Results on the fabrication and characterization of NNO cathode supported SOFC will be presented. The tubes were fabricated by cold isostatic pressing (CIP) using NNO powders and corn starch as the pore former. The electrolyte (GDC based) was deposited by wet powder spray (WPS) on top of the pre-sintered tubes and then co-sintered. Finally, a NiO-GDC paste was dip-coated as the anode.

Optimization of the fabrication process as well as the electrochemical performance of single cells will be further discussed.

A0707

Processing of graded anode-supported micro-tubular SOFCs via aqueous gel-casting

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Abstract

A simple gel-casting method was successfully combined with the spray-coating technique to manufacture graded anode-supported micro-tubular solid oxide fuel cells (MT-SOFCs) based on samaria-doped ceria (SDC) as an electrolyte. Micro-tubular anodes were shaped by a gel-casting method based on a new and simple forming technique that operates as a syringe. The aqueous slurry formulation of the NiO-SDC substrate using agarose as a gelling agent, and the effect of spray-coating parameters used to deposit the anode functional layers (AFLs) and electrolyte were investigated. Furthermore, pre-sintering temperature of anode substrates was systematically studied to avoid the anode-electrolyte delamination and obtain a dense electrolyte without cracks, after co-sintering process at 1450 ºC. Despite the high shrinkage of substrate (~70%), an anode porosity of ~37% was achieved. MT-SOFCs with ~ 2.5 mm of outer diameter, 350 μm thick substrate, 20 μm thick AFLs and 15 μm thick electrolyte were successfully obtained. The use of AFLs with 10:90, 30:70 and 50:50 wt.% NiO-SDC allowed to obtain a continuous gradation of composition and porosity in the anode-electrolyte interface.

A0708

New Methods of Electrode Preparation for Micro-Tubular Solid Oxide Fuel Cells

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Abstract

A new method of electrode production for micro-tubular solid oxide fuel cells (mSOFCs) has been investigated previously with the aim of improving their RedOx and thermal cycling resistance[1]. The microstructure of porous YSZ layers is shown to have a strong effect on effective infiltration resulting in improvement of cell power[2]. For this work, tubes consisting of a co-extruded dense YSZ electrolyte and porous NiO-YSZ anode were modified with different cathodes and anode infiltration to investigate the effects on both power and thermal cycling tolerance.

Several variables were investigated, namely the type of cathode (produced by infiltration of LSM into a porous YSZ matrix or by hand-painting of an LSM-YSZ ink), the type of pore former used in the cathode and the infiltration of the anode (no infiltration, or with infiltration steps using a co-precipitated Ni-SDC solution, or SDC solution). The overall aim of this work is to produce more strongly-performing cells, monitoring cell stability upon thermal cycling. As the anode of these cells is vulnerable to RedOx cycling, only thermal cycling was tested here.

Anode infiltration was shown to have a particularly advantageous effect on performance, raising the peak power and reducing the degradation in peak power seen after aggressive cycling. Cell power can be improved by LSM infiltration into a porous YSZ layer when thickness of the YSZ layer is optimised and there is sufficient LSM. When PMMA was used as the pore former in the porous YSZ matrix, a slightly better cell performance is obtained compared with graphite as the pore former. For studying the effect of thermal cycling on cell stability, monitoring the power variation is found to be a more reliable tool than OCV measurements.

A0709

Sol-Gel Process to Prepare Hierarchical Mesoporous Thin Films Anode for Micro-SOFC

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Abstract

Derived ceria–based materials electrodes nanoarchitectures were synthesized through the sol–gel approach and a one-step thermal treatment. The 3–D network is constituted of non–agglomerates nanoparticles (2 to 4 nm at 600°C) of NiO and Gd–doped ceria in anode. In this arrangement, particles in the nanoscale are kept because of the presence of secondary phases, both NiO and pores. The effect of the microstructure on their electrical conductivities in the range of 400-600°C is low, due to their stability. As the particle size is controlled, these mesostructured films can be used as model to study the impact of the size of the particle on the transport of both ions and electrons. After reduction, the Ni/GDC cermet microstructures evolved with time for temperature higher than 400°C. The electrical performance of this cermet thin film was measured in a single gas atmosphere setup by impedance spectroscopy. The electrical results will be discussed as function of both the cermet composition and the microstructure.

A0710

$Sr_2Fe_{1.5}Mo_{0.5}O_{6-\delta}$ as symmetrical electrode for micro SOFC

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Abstract

Micro solid oxide fuel cells (SOFCs) have recently appeared as an alternative for energy suppliers in portable electronics. The development of these micro devices has been mainly focused on a very singular geometry, i.e. free-standing thin membranes. The PEN element (electrode/electrolyte/electrode tri-layer) is self-supported on micro-platforms used as substrate. Recent publications showed the potential use of different substrate materials (silicon, Foturan®, metals…) and electrolytes (YSZ, CGO…) [1,2]. However, most of the works use only precious metals as porous electrodes, although the state-of-the-art materials used in SOFC suggest us to use ceramics as LSM, LSCF… or cermets (Ni-YSZ). The use of more simple electrodes (metals) is mainly due to the complexity of the PEN element, i.e. very thin and self-supported membrane. Although the use of ceramic electrodes with similar mechanical properties than the electrolyte would be beneficial for the membrane as they would give the thin electrolyte more strength, when using different materials at each side of the electrolyte membrane the compensation of stresses along the membrane becomes very important. Cracks or other defects can appear during thermal cycling, provoking short-circuits through the thin electrolyte film.
In this sense, the use of symmetrical electrodes appears as a good solution as the distribution of stresses would be homogeneous. In this work, the authors present a novel symmetrical ceramic electrode to be used as both cathode and anode on micro SOFCs: $Sr_2Fe_{1.5}Mo_{0.5}O_{6-\delta}$ (SFM). A recent communication by Liu et al. [3] showed the potential use of SFM as symmetrical electrode in SOFCs, proving its capability of working both in reducing and oxidizing atmosphere. The authors have optimized the deposition of SFM by Pulsed Laser Deposition (PLD) over different substrates, including PLD deposited YSZ thin films. Thus, the whole PEN element based on a SFM/YSZ/SFM tri-layer can be fabricated completely by PLD.

A0711

Fabrication of cathode supported tubular SOFC through iso-pressing and co-firing route

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Abstract

In the present work, LSCM cathode supported tubular SOFC has been fabricated by a co-pressing and co-firing route. The one-end-closed tubular cathode support was initially fabricated by cold isostatic pressing (CIP) and subsequently coated with YSZ electrolyte and NiO-YSZ anode layers. The coated tube was co-pressed in CIP and co-fired at 1350 °C. Microstructural investigation indicated formation of dense electrolyte coating and porous electrodes. Symmetrical cells in planar disc configuration have been fabricated to simulate the interfaces of tubular cell and area specific resistance (ASR) for interfacial polarisation has been determined by electrochemical impedance spectroscopy (EIS) technique. The results suggest that the electrode-electrolyte interface of a cell fabricated by co-pressing and co-firing approach has good adherence and reasonably low polarisation resistance and hence, the present technique can be a viable one for fabrication of LSCM cathode supported solid oxide fuel cell.

A0712

2R-Cell™: A redox anode supported cell for an easy and safe SOFC operation

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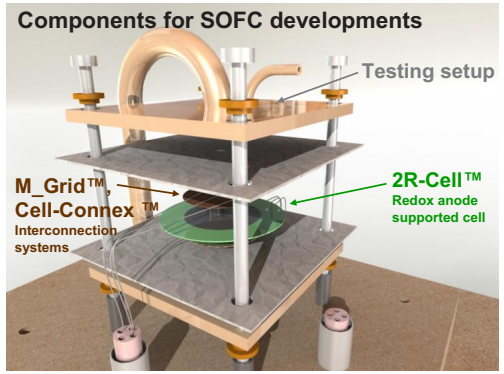
Abstract

Thank to their high power density in a wide range of temperature, anode supported thin film electrolytes are nowadays the mostly used cells in the SOFC area. Unfortunately, the latter suffer from an important problem: they are totally destroyed when re-oxidation occurs in the anode chamber. This happens, for instance when fuel supply inappropriately stops. Cell peripheral re-oxidation is another well known figure where failures are initiated. In all cases, when re-oxidation starts, the stack quickly undergoes a fatal destruction and the SOFC system definitely falls down.

Fiaxell has developed **2R-Cell™**, an anode supported thin electrolyte (ASC) that withstands multi redox cycles without being damaged and with equivalent electrochemical performances than actual state of the art for standard ASC. 2R-Cell™ is manufactured with very standard materials (nickel oxide and zirconia) and is manufactured through a proprietary technology. Fiaxell is also offering other components for SOFC R&D developments and SOFC quick and reproducible measurements.

- **Testing set-up:** which allows for very quick cell testing, gives reproducible results with up to 85 (%) of fuel utilization obtainable on small cell dimension
- **M_Grid™:** a Crofer 22APU micro grid to replace the expensive gold mesh for button cell testing. Also useful to increase the current collection (planar or tubular stack)
- **Cell-Connex™:** an interconnection system that has been designed to minimize the current collection resistance



- **Special inks:** easy cleaning water soluble inks have been developed for screen printing, tape casting and casting. For each application, parameters such as viscosity and evaporation rate can be adjusted on a full scale range

For more details: http://www.fiaxell.com

A0713

Chemistry of Electrodes in Solid Oxide Fuel Cells

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Abstract

A selection of materials of the formula $La_{1-x}Mn_xMn_{1-x}Ti_xO_{3-\delta}$ were synthesised for the range of $0<x\leq0.3$. These were demonstrated to display an acceptable level of electronic conductivity in air at working temperatures for SOFCs. In addition they are redox stable, and while they still show some electronic conductivity in a $5\%H_2/N_2$ environment this is substantially lower than in air (0.4 S cm^{-1} max against 12 S cm^{-1} max).

A second series of materials based around $SrFeO_{3-y}$ featuring the successful incorporation of Si into the cubic perovskite structure was synthesised. This series showed retention of conductivity up to and including the 10% doped variant, $SrFe_{0.9}Si_{0.1}O_{3-y}$. Conductivity measurements in 5% H_2/95% N_2 showed that a significant reduction in the conductivity was observed above 550°C, attributed to the reduction of the Fe oxidation state down to Fe^{3+}. The work provides further evidence to illustrate that Si can enter the perovskite structure, and the high conductivities in air suggest the potential for SOFC cathode applications, while the stability under H_2 suggests that these could be examined also as cermets in conjunction with Ni.

This presentation will also contain a brief overview on the fabrication of anode supported microtubular solid oxide fuel cells (SOFCs) at the University of Birmingham, including details of extrusion techniques and sintering profiles that have been refined to give the most reliable results for industry standard materials (YSZ/NiO). The limitations of these materials are also discussed, providing an argument for the move towards alternative ceramics.

A0714

Anode Morphology and Performance of Micro-tubular Solid Oxide Fuel Cells Made by Aqueous Electrophoretic Deposition

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Abstract

Anode-supported micro-tubular solid oxide fuel cells (SOFCs) were manufactured by a novel method using aqueous electrophoretic deposition (EPD). The process of these micro-tubular SOFCs included consecutive aqueous EPDs of a porous anode layer (Ni-YSZ), a dense electrolyte layer (YSZ), and a porous cathode layer (LSM) onto a thin wire electrode, followed by stripping, drying, and a single-step co-sintering. The microstructure of the micro-tubular SOFCs, including the thickness and porosity of each layer, was controlled by the processing parameters such as solid loading, current density, deposition time, and sintering temperature. In particular, the effects of the morphology of the anode layer on the electrochemical performance of such micro-tubular SOFCs were investigated and discussed based on the impedance and V-I-P analyses.

A0715

Performance of microtubular solid oxide fuel cells for the design and manufacture of a fifty watts stack.

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Abstract

The main advantage of tubular SOFC cells against the planar is the facility they present in the sealing. Furthermore, the microtubular cells can support a faster warm up time and a higher volumetric energy density.

Anode supported microtubular cells have been produced, analyzed and characterized. The cell characteristic are, anode Ni-YSZ 400µm (50vol% Ni and YSZ 50vol%), electrolyte 8YSZ of 15-20µm and bi-layer LSM-YSZ cathode (one functional layer of 20µm 50vol% LSM- 50vol% YSZ and a current collector layer of 20µm 80vol% LSM - 20vol% YSZ).
We have operated at different temperatures (750ºC - 900ºC) to fully characterized the cells by AC impedance spectroscopy and also by current density-voltage measurements.

The integration feasibility of the stack in a portable power module (a 50W microtubular Ni-YSZ anode supported SOFC stack) is demonstrated by the conceptual design of the system. An energy balance is simulated with Matlab Simulink ®. The operation modes of the system, efficiency and convection inside the stack are studied via the Simulink® simulation. An electrical simulation is also done for the complete cell characterization.
A modular 3D design of the stack is also drawn using Solid Works ®. This model is used to study the flow paths through the stack.

The model will be validated with the fabrication of an experimental microtubular cell stack. Several single cells have been fabricated and their performance will be shown. An experimental 2 cell-stack has been also built and tested with a total power of 0.9W. The work is under continuous development for the fabrication of a first prototype.

A0716

Processing of Lanthanum-doped Strontium Titanate Anode Supports in Tubular, Solid-Oxide Fuel Cells

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Abstract

This work focuses on ceramic-processing techniques for fabrication of tubular solid-oxide fuel cells (SOFCs) based on perovskite anode supports. Two types of SOFCs are fabricated; both utilize a $Sr_{0.8}La_{0.2}TiO_3$ / $Y_{0.08}Zr_{0.92}O_2$ (SLT-YSZ) anode support, a YSZ electrolyte and an $(La_{0.8}Sr_{0.2})_{0.98}MnO_{3-x}$ - YSZ (LSM-YSZ) cathode. Once cell includes no additional catalyst, and the second cell utilizes a thin Ni-YSZ anode-functional layer (AFL) at the interface between the SLT-YSZ support and the YSZ electrolyte.

The NiO present in the anode functional layer is found to act as a sintering aid to the SLT support. This causes rapid densification in the support near the NiO/anode-support interface, and internal stress that cause cell fracture during sintering. This localized sintering is alleviated through addition of a diffusion barrier layer between the SLT-YSZ support and the Ni-YSZ anode functional layer. The barrier layer is comprised of $Ga_{0.1}Ce_{0.9}O_2$ (GDC) and YSZ, resulting in a five-layer membrane-electrode assembly.

Stability of these two materials sets throughout the high-temperature fabrication processes is confirmed using x-ray diffraction, dynamic shrinkage dilatometry, and electron microscopy. Cell performance is measured under humidified hydrogen at 800 °C; results are used to infer the effectiveness of the added catalyst, and the viability of perovskite anode supports in tubular SOFC architectures.

A0901

Micro-SOFC supported on a porous Ni film

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Abstract

Micro-SOFC, miniaturized Solid Oxide Fuel Cell for low temperature operation, is being developed for the power source of portable electronic devices. Reducing thickness of the cell component, especially electrolyte, with thin film process is needed to avoid large Ohmic resistance below ~500°C. However, as the cell components are getting thinner into the sub-micrometer scale, the strength of the cell is also reduced of necessity.

One of the solutions is to adopt a metallic support to improve the mechanical strength of thin ceramic components. The porous structure is needed for gas diffusion. Smooth surface is also needed for the deposition of thin and dense electrolyte. Lithography and dry/wet etch are often used to realize the contradictory structure of the support but the processes are so expensive. In this study, we have fabricated micro-SOFC supported by a nickel film required no complex lithography and etch process but only a simple printing method with metal paste.

Ni was chosen as the support material and the porous film was fabricated by screen-printing on ceramic substrate and then sintering in reducing atmosphere. Microstructure of the porous film was optimized via controlling nickel particles and sintering temperature. The size of particles was about 200-300nm with spherical shape, and the optimum sintering temperature is 550°C. Acceptor-doped ceria is one of the promising electrolyte materials for low temperature operation due to its high ionic conductivity. However, the doped ceria was seldom applied to micro-SOFC as the electrolyte. Gd-doped ceria was deposited by Pulse Laser Deposition (PLD) on the nickel support and thickness of the electrolyte was under 1μm. (LaSr)CoO_3 was used as a thin film cathode for the cell and Pt was coated on the top of the cell for current collection.

The fabricated cell was electrochemically tested below 450°C. Wet hydrogen and air were used as fuel and oxidant gases, respectively. The cell exhibited 0.91V of Open Circuit Voltage (OCV). It meant that no fatal cracks and pinholes of thin film electrolyte were shown. However, delamination was observed at the interface between electrolyte and a thick Ni film to result in the low power density of the cell. This cell has the potential to enhance strength and may be used as a low-temperature SOFC.

A0902

Thin Electrolytes on Metal-Supported Cells

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Abstract

In recent years metal-supported fuel cells (MSC) attract more and more interest as auxiliary power units (APU).To reduce the starting temperature to ~ 650°C and to improve the power density of the MSCs, thin electrolytes with thickness in the range of some micrometers are needed. To reach these goals, Forschungszentrum Jülich is cooperating with industrial partners such as Plansee SE.

The focus of the present work is the development of thin film electrolytes using a sol-gel spin-coating process. This method makes it possible to prepare fine layers which are following the surface characteristics of the base layer underneath. The porous metallic substrates are made of ferritic oxide dispersion strengthened Fe-Cr alloy (ITM) delivered by Plansee. A big challenge in coating these coarse metallic supports is their high roughness and porosity in comparison to state-of-the-art ceramic substrates of SOFCs. To consider these characteristics, the developed anode of nickel and 8 mol% yttria-stabilized zirconia (8YSZ) is made of graded functional layers which are gradually reducing roughness and porosity.

The quality of the thin electrolyte layer depends on the surface's microstructure of the anode to be coated. Influencing variables are the roughness, the pore size and the depth of the pores. To understand the dependencies between these influencing variables and the coating properties, analyses with different optical measurement methods were carried out, employing detection steps ranging from 140 nm to some μm in order to show the 3D structure of the anode surface. It is shown that pores with a length smaller than 4 μm and steep flanks can be covered with sols with comparative small particles of ~50 nm. Surface roughness determination shows that the roughness of the anode's surface is a limiting factor to the thickness of the electrolyte to at least 500 nm.

The electrolyte is fabricated of graded functional layers as well in order to use the better activity of very small 8YSZ particles during the sintering process. This allows the production of electrolytes in the range of ~1 μm thickness with leak rates of 1-3 10^{-4} hPa dm³/ (s cm²) of MSCs with a reduced anode. These leak rates are comparable to those of anode-supported cells (ASC).

A0903

Advances in Metal Supported Cells in the METSOFC EU Consortium

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Abstract

Employing a mechanically robust metal support as the structural element in SOFC has been the objective of various development efforts. The EU-sponsored project “METSOFC”, completed at the end of 2011, resulted in a number of advancements towards implementing this strategy. These include robust metal supported cells (MSCs) having low ASR at low temperature, incorporation into small stacks of powers approaching ½kW, and stack tolerance to various operation cycles.
DTU Energy Conversion's (formerly Risø DTU) research into planar MSCs has produced an advanced cell design with high performance. The novel approach has yielded roboust, defect-free cells fabricated by a unique and well-tailored co-sintering process. At low operation temperatures (650°C), these cells have shown remarkable ASRs: 0.35 Ωcm^2 in cell tests (16 cm^2 active area) and under 0.3 Ωcm^2 in button cells (0.5 cm^2 active area). Further success was attained with even larger cell areas of 12 cm squares, which facilitated integration into stacks at Topsoe Fuel Cell. Development of MSC stacks showed that the MSCs could achieve similar or better performance, compared to SoA anode supported ceramic cells. The best stacked MSCs had power densities approaching 275 mW/cm^2 (at 680°C and 0.8V). Furthermore, extended testing at AVL determined extra stack performance and reliability characteristics, including behavior towards sulfur and simulated diesel reformate, and tolerance to thermal cycles and load cycles. These and other key outcomes of the METSOFC consortium are covered, along with associated work supported by the Danish National Advanced Technology Foundation.

A0904

Stack Tests of Metal-Supported Plasma-Sprayed SOFC

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Abstract

The development of metal-supported plasma-sprayed SOFC has shown impressive progress in recent years. The main focus of this development was to create a functional stack. Integration of the cell into interconnects has been simplified leading to a lightweight cassette design with a fully integrated cells. Short stacks have been tested for proof of concept with good results at thermal and redox cycling. This shifted the main tasks of the development to scaling up the number of layers and increasing the lifetime of the stacks.
In the project MS-SOFC new cassettes using the Plansee ITM alloy have been developed and new plasma spray processes for the electrode layers were introduced. Changes in the manufacturing processes also allowed for the reduction of the number of manufacturing processes for the cassette.
Stacks were built up using the new developments. Two 10-layer stacks, one with a vacuum plasma sprayed electrolyte and one with a low pressure plasma sprayed electrolyte, were assembled to evaluate the power density and one 4-layer stack was used for long-term testing. Results of these experiments are presented in this paper.

A0905

Tubular metal supported solid oxide fuel cell resistant to high fuel utilization

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Abstract

Tubular metal supported SOFC technology has successfully been developed over the past years with the aim at small domestic CHP and portable systems. First generation of cells have been successfully tested up to 2000 h under current loading and more than 520 thermal cycles had been demonstrated at low humidification conditions (3% H_2O/H_2). However, good resistance against oxidation due to high fuel utilization was not achieved. A special effort was then devoted to determine the reason for the catastrophic degradation observed during operation at high fuel utilization conditions. Tests performed in metal support, diffusion barrier layer and anode structured samples under high humidification atmospheres (50% H_2O/H_2, 800ºC) have demonstrated that modifications in the diffusion barrier layer, improve significantly the resistance to oxidation of the metallic support and cells, achieving more than 500 hours with almost no degradation. Furthermore, a second generation of cells that can operate at high fuel utilization conditions for more than 1000 hours have been successfully demonstrated.

A0906

Development and Industrialization of Metal-Supported Solid Oxide Fuel Cells

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Abstract

During the last decade metal-supported solid oxide fuel cells (MSCs) have attained increasing interest for electrical power supply in mobile applications, e.g. in so called “auxiliary power units” (APUs), especially for diesel-powered heavy trucks. Compared with anode-supported cells (ASCs), which are primarily world-wide seen for those application, this cell technology promises significant advantages, for example, an increased resistance against mechanical and thermal stresses, re-oxidation tolerance and a significant potential for material cost reduction.

Based on a powder-metallurgically manufactured (P/M) porous substrate, that consists of the well-known P/M FeCr-ITM-alloy, Plansee pursues to establish its own industrial fabrication to offer customers high performance metal-supported cells and “ready to stack”-components. By using thin P/M interconnector sheets, Plansee’s latest concept of metal-supported cells allows to build-up stacks with significantly reduced weight, an increased cell performance and the ability to meet the cost requirements for cell, repeat unit, and stack.

Benefiting from a strong cooperation with Forschungszentrum Jülich and Karlsruhe Institute of Technology (KIT) – in the scope of the NextGen MSC-Project (financially supported by the German Ministry of Economics and Technology (BMWi)) – a novel cell configuration for an industrialized manufacturing route could be developed and characterized successfully. At present, a first pilot fabrication for this novel cell configuration has been established at Plansee. The paper gives an overview about the cell development process as well as about the manufacturing route for cost effective metal-supported cells and repeat-units.

A0907

Recent Developments in Design and Processing of the SOFCRoll Concept

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Abstract

The SOFCRoll design is a novel design based on a double spiral design, which combines the structural advantages of tubular geometries with the processing advantages of the thick film techniques widely utilised by planar systems. The design is self supporting due to its tubular form and minimal sealing is required compared to other designs as both anode and cathode exhausts are combusted along the edge of the cell. The SOFCRoll is a minimalist concept offering the lowest possible cost in terms of materials use and manufacturing time. In the initial design the multiple cell layers were brought together using a simple tape casting, lamination, folding and rolling procedure and then fired in a single high temperature step. However this resulted in relatively thick layers which resulted in significant ohmic and diffusion losses.

We are currently investigating a second generation design which seeks to optimise layer thickness appropriate to their function. To this end the new cells have been developed incorporating screen printed layers where a reduced thickness is desired, such as electrolyte and electrodes and retaining tape casting where thicker layers are required such as current collection. The screen printed layers are deposited onto the green tapes before lamination and cofiring as before. In order to improve gas flow around the spiral we have also investigated the incorporation of integral gas flow channels into the spiral. These were formed by printing lines of graphite based inks which burnt out during firing to leave hollow channels. Initial tests of the 2nd generation SOFCRolls have shown open circuit voltages close to 1V and a cell power output of over 350mW at 700°C.

This paper will discuss the design methodology behind the 2nd generation cells, recent process development activities to attain this, along with recent test results, possible applications for the concept and future development directions.

A0908

Infiltrated $SrTiO_3$:FeCr-based anodes for metal-supported SOFC

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Abstract

The concept of using highly electronically conducting backbones with subsequent infiltration of electrocatalytic active materials, has recently been used to develop an alternative SOFC design based on a ferritic stainless steel support. The metal-supported SOFC is comprised of porous and highly electronically conducting layers, into which electrocatalytically active materials are infiltrated after sintering.
This paper presents the first results on single cell testing of 25 cm^2 cells with 16 cm^2 active area of a metal-supported SOFC were the anode backbone consists of a composite of Nb-doped $SrTiO_3$ (STN) and FeCr. Electrochemical characterization and post test SEM analysis have been used to get an insight into the possible degradation mechanisms of this novel electrode infiltrated with Gd-doped CeO_2 and Ni. Accelerated oxidation/corrosion experiments have been conducted to evaluate the microstructural changes occurring in the anode layer during testing. The results indicate that the STN component in the anode seems to have a positive effect on the corrosion stability of the FeCr-particles in the anode layer.

A0909

Break-down of Losses in High Performing Metal-Supported Solid Oxide Fuel Cells

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Abstract

Metal supported SOFC designs offer competitive advantages such as reduced material costs and improved mechanical robustness. On the other hand, disadvantages might arise due to possible corrosion of the porous metal parts during processing and operation at high fuel utilization.
In this paper we present the results of performance and stability improvements for a metal supported cell developed within the European project METSOFC and the Danish National Advanced Technology Foundation. The cells consist of a porous metal backbone, a metal / zirconia cermet anode and a 10ScYSZ electrolyte, cofired in hydrogen. The electro-chemically active parts were applied by infiltrating CGO-Ni precursor solution into the porous metal and anode backbone and screenprinting $(La,Sr)(Co,Fe)O_3$-based cathodes. To prevent a solid state reaction between cathode and zirconia electrolyte, CGO buffer layers were applied in between cathode and electrolyte.
The detailed electrochemical characterization by means of impedance spectroscopy and a subsequent data analysis by the distribution of relaxation times enabled us to separate the different loss contributions in the cell. Based on an appropriate equivalent circuit model, the ohmic and polarization losses related to the gas diffusion in the metal support, the electrooxidation in the anode functional layer and the oxygen reduction in the mixed ionic electronic conducting cathode were determined. An additional process with a rather high relaxation frequency could be attributed to the formation of insulating interlayers at the cathode/electrolyte-interface. Based on these results, selective measures to improve performance and stability, such as (i) an improved PVD-deposited CGO buffer layer, (ii) LSC-CGO based in-situ sintered cathodes and (iii) reduced corrosion of the metal support were adopted and validated.

A0910

Low Temperature Thin Film Solid Oxide Fuel Cells with Nanocomposite Anodes

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Abstract

Thin film micro-solid oxide fuel cells (μSOFCs) utilizing ruthenium (Ru) - gadolinia-doped ceria (CGO) nano-composite anodes were fabricated and investigated for direct methane operation. Thin film of 8 mol% yttria-stabilized zirconia (YSZ) with a thickness of ~100 nm was fabricated as free-standing electrolytes, with ~50 nm thick porous platinum (Pt) cathode electrodes. Ru-CGO thin films were deposited on YSZ electrolytes as anode electrodes. μSOFCs were tested with room temperature humidified methane as the fuel and air as the oxidant under constant cell voltage condition. Microstructures of the composite anodes and Pt metal cathodes after the fuel cell test were investigated and compared through SEM study, indicating good morphological stability of the composite anodes.
Morphologies of Ru-CGO composite thin films deposited on YSZ thin films on silicon substrates were investigated, and was found that the composite films exhibit highly granular structure compared to the films deposited on single crystal substrates. Cross sectional SEM revealed columnar structures of these highly granular films.
These results suggest physical vapor deposition as a promising route to fabricate electrically connected nanocomposite metal-oxide mixtures for SOFC electrodes.

A0911

Quality Assurance Methods for Metal-Supported Cells

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Abstract

Stationary SOFC systems for the efficient generation of electricity have been successfully commercialized during the past years. These systems rely on well proven designs such as anode- and electrolyte-supported cells (ASCs, ESCs). In contrast, innovative concepts including metal-supported cells (MSCs), have attained increasing interest for mobile applications, e.g. for the on-board electrical power supply by auxiliary power units (APUs) in heavy-duty trucks. MSCs promise significant progress, such as increased mechanical robustness, excellent red-ox stability and major cost reduction.

Only recently, a pilot fabrication for MSC cells based on a powder metallurgical manufacturing route has been set up at Plansee. In this facility, porous metallic FeCr-substrates serve as a tough metallic backbone for ceramic membrane-electrode assemblies (MEA). The MEA is deposited onto the substrate by a consecutive sequence of printing, sintering and PVD thin-film manufacturing steps. The process generates MSCs with a fully dense thin-film PVD-electrolyte and porous electrodes, specifically a multi-layered anode with a gradient microstructure. Finally, the MSC cells are integrated into ready-to-stack components (“repeat units”) by laser-welding the substrate into a metal frame and an integrated housing.

The industrialization of MSC cells demands rigorous quality-assurance (QA) processes from the very beginning of pilot production. For that purpose, Plansee has developed and integrated reliable test procedures and implemented them into a robust QA process. This paper describes key QA test systems and procedures and demonstrates their functionality and reliability.

A1001

Nickel agglomeration in Solid Oxide Fuel Cells under different operating conditions

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Abstract

In order to get a clear picture on Ni agglomeration, excessive work has been done in our group to quantify the Ni-particle growth with respect to (1) temperature, (2) time, (3) water vapor and (4) redox-cycling. The quantification of SEM images has been realized by using an algorithm for the continuous particle size distribution. The temperature dependency of the Ni-radius growth follows an Arrhenius-type equation. Significant Ni coarsening starts above 850°C. The presence of water vapor significantly accelerates the Ni agglomeration in comparison to low water vapor concentrations. This is believed to be mainly caused by an evaporation/condensation mechanism of the volatile $Ni(OH)_2$, linked with a surface diffusion mechanism. The trend of the Ni radius over 2000 hours could be described with $t^{1/4}$ type law very similar to the classical Ostwald ripening. After longer exposure times the results from the image analysis indicate that Ni loss may occur especially in the electrochemically active layer. Furthermore, the experiments indicate that the Ni agglomeration is not just linked with the water vapor concentrations but also with the actual volume flux of water vapor in/over the electrode. Significant Ni agglomeration was also observed after redox-cycling of a Ni/CGO anode and quantification of the microstructures, respectively. However, the mechanism is a complex interplay of Ni transport linked with thermo-mechanical aspects. The Ni transport is believed to be linked with the nm sized NiO crystals which grow on the particle surface upon oxidation and vanish immediately after re-reduction.

A1002

Durability and Performance of High Performance Infiltration Cathodes

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Abstract

High performance cathodes are a requirement for solid oxide fuel cells (SOFCs) operating at low temperature. In the present work, cathodes are prepared by screen printing a layer of $Ce_{0.9}Gd_{0.1}O_{1.95}$ (CGO10) with pore former onto an electrolyte. The 25-40 µm sintered porous CGO layer will be referred to as a backbone structure. In the CGO backbone structure, the nitrates corresponding to the following nominal compositions have been infiltrated: $La_{0.6}Sr_{0.4}Co_{1.05}O_{3-\delta}$ (LSC), $LaCoO_{3-\delta}$ (LC) and Co_3O_4. High temperature X-ray diffraction (HT-XRD) (up to 900°C) indicated that for LSC and LC a number of different phases are present and not just a single phase perovskite. All electrodes were characterized as symmetric cells in the temperature range 400-900°C. At 600°C, in air, the polarization resistance varied as: 0.062 Ω cm^2 (LSC40) < 0.079 Ω cm^2 (LC) < 0.27 Ω cm^2 (Co). The electrochemical performance of the cathodes is found to depend on the maximum temperature the infiltrate had been subjected to. This correlation is, based on HT-XRD, SEM and electrical conductivity measurements, suggested to originate from a complex interplay between the formation of electronic conducting phases, the formation of catalytically active phases, the surface area of the catalysts and the percolation of the electronic conducting phase. An extended test (450 h) of infiltrated LSC40 was performed in air showing that the polarization resistance increased from 0.041 Ω cm^2 to 0.069 Ω cm^2 at 600°C, with a final degradation rate of only 11 mΩ cm^2 kh^{-1}. This clearly demonstrates that these electrodes are robust and durable for long term operation. The increase in polarization resistance is attributed to the coarsening of catalytically active particles.

A full cell with the active area 4 cm × 4 cm with a porous CGO backbone infiltrated with LSC40 was prepared on a tapecast and co-sintered structure comprised of a NiO/YSZ support, ScYSZ/NiO anode, ScYSZ electrolyte and a CGO barrier layer. The cell was tested from 850 - 650°C in 50°C steps. At 700°C the power density reached 0.58 W cm^{-2} at a cell voltage of 0.6 V. Based on the symmetric cell measurements, the cathode response is estimated to only constitute approximately 7% of the overall ASR. The cell was tested for 1500 h at 700°C and 0.5 A cm^{-2} (60% fuel and 20% air utilization) without measurable degradation, consistent with post-test microstructural analysis that showed negligible changes in the cathode microstructure.

A1003

Chromium Poisoning of $LaMnO_3$-based Cathode within Generalized Approach

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Abstract

Recent progress of the NEDO project on durability/reliability of SOFC stacks will be reported with an emphasis on the achievement of Mitsubishi Heavy Industries' segment-in-series cells in which the lanthanum manganite based cathode has been improved recently. The cell durability tests were made by CRIEPI on their cells with/without doped ceria interlayer to check plausible effects of microstructure change and of chromium poisoning. Improved cells exhibit essentially no degradation for 10,000 h and also strong tolerance against the Cr contamination from the stainless steel tubes (less than 1 mV/1000 h). These new features in durability of MHI's segment-in-series cells are discussed within the generalized degradation model developed inside the NEDO project. In particular, the extremely small overpotential can be considered to be effective in lowering the Cr poisoning by reducing the driving forces for the electrochemical Cr deposition at the electrochemically active sites. Insertion of doped ceria is also useful in preventing the Cr deposition of enhancing the volatilization of deposited Cr with water vapors emitted as a part of cathodic reactions of protons in ceria. Some thermodynamic considerations reveal that the initial composition of LSM cathode characterized in terms of the A-site deficiency and the Sr content is important to determine the microstructure change due to the chromium dissolution into the B-sites in the perovskite lattice. Discussions are also made on other roles of doped ceria to prevent possible deterioration of Mn-dissolved electrolyte by lowering the Mn dissolution into YSZ.

A1004

Chromium poisoning of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ in Solid Oxide Fuel Cells

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Abstract

In service the interconnect alloys used in intermediate temperature SOFCs form chromium-rich oxidation scales which give rise to chromium-containing vapours under the oxidising conditions of the cathode side. As a result, the transfer and deposition of chromium species into the cathode can severely degrade its performance and is known as 'chromium poisoning'. The objective of this study, is to investigate the relationship between the amount of chromium deposited on $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$, LSCF (6428), cathodes, which are often used at intermediate temperatures, and their electrochemical performance and clarify further the poisoning mechanism.

LSCF cathodes were screen printed as symmetrical structures onto $Ce_{0.9}Gd_{0.1}O_{1.95}$ (CGO) electrolyte pellets and contaminated to different Cr levels by infiltration with $Cr(NO_3)_3$ solutions. Their electrochemical performance was characterised by impedance spectroscopy in the temperature range 500 – 800°C. The results show that even very low levels of Cr contamination give a significant increase in the area specific resistance (ASR) of the LSCF cathodes, which increases as the level of Cr contamination increases. However the activation energies for the ASR and surface exchange are not affected by the Cr contamination. This indicates that the Cr poisoning mechanism involves the de-activation of sites for oxygen exchange on the LSCF surface and that the cathode's residual activity is by means of remaining active sites.

A1005

Evaluation of Sulfur Dioxide Poisoning for LSCF Cathodes

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Abstract

$La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$ (LSCF6428) cathode degradation was investigated at T = 800 °C for 100 h by varying the flow rate of SO_2 (25, 50, and 90 mL/min), which affects the amount of the supplied SO_2 under $P(SO_2)$ = 0.1 ppm. When the amount of SO_2 increased, the performance degradation became critical, suggesting that the performance degradation depends on the total of SO_2 supply. When the amount of SO_2 was small (25 mL/min), sulfur was mainly trapped at the cathode surface. On the other hand, with increasing the amount of SO_2 (50 or 90 mL/min), the sulfur was concentrated in the vicinity of the LSCF6428/GDC interface.

A1006

Reversibility of Cathode Degradation in Anode Supported Solid Oxide Fuel Cells

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Abstract

Mixed ionic electronic conducting (MIEC) cathodes are indispensable for high performance anode supported fuel cells (ASC's). In contrast to cells with electronic conducting cathodes the cells with MIEC cathode like $La_{0.58}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF) show higher degradation rates. The identification and reduction of the cathode degradation is a crucial point for a target oriented development of ASC's.
This study tracks the reversibility of cathode degradation in ASC's. A wide set of impedance spectra were sampled at 600, 750 and 900 °C over the entire operation time of 1000 h. Moreover, after long term tests at intermediate temperatures, ASC's were exposed to higher temperatures again. Afterwards, the various anodic and cathodic contributions to the overall polarization loss of all ASC's were quantified by our well-tried equivalent circuit model. For this purpose, the impedance data sets were evaluated subsequently by (i) a DRT analysis (distribution of relaxation times) followed by (ii) a CNLS fit.
The analysis of all data sets leads to the surprising outcome that the temperature history of an ASC under test has a remarkable effect on the cathode degradation. The cathode resistance decreases from 0.057 Ωcm^2 to 0.010 Ωcm^2 at 750 °C after an intervening 900 °C step. XRD measurements of the LSCF cathode reveal a phase transition between 750 °C and 900 °C as most probable cause and effect. These results are essential to understand the cathode degradation and for choosing the operating temperature in anode supported fuel cells.

A1007

Multilayer tape cast SOFC Effect of anode sintering temperature

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Abstract

Multilayer tape casting (MTC) is considered a promising, cost-efficient, up-scalable shaping process for production of planar anode supported solid oxide fuel cells (SOFC). Multilayer tape casting of the three layers comprising the half cell (anode support/active anode/electrolyte) can potentially be cost-efficient and simplify the half-cell manufacturing process. Fewer sintering steps (co-sintering), as well as fewer handling efforts, will be advantageous for up-scaled production.

Previous reports have shown that our laboratory produces mechanically strong, high performing anode supported SOFC, with high reproducibility, by tape casting of the anode support [1]. Recent initial results obtained on SOFC with half-cells produced by successive tape casting (MTC) of anode support, anode and electrolyte layers, followed by co-sintering of the half-cell, showed increased performance and stability upon FC operation compared to SOFC with half-cells produced by tape casting of anode support but spraying of active anode and electrolyte [2]. These results have initiated further work on MTC half cells. Initial MTC production results have shown that it is possible to co-sinter the MTC anode half cells in a rather large "temperature-window".

To increase our understanding of the MTC process, obtained microstructures and the resulting electrochemical performance of these SOFC, we here report a study of MTC based cells. The half-cells have been produced and co-sintered at 5 different temperatures from 1255 °C to 1335 °C. This study investigates the effect of the sintering temperature on the anode microstructure analysed via electron microscopy images; and correlate it with electrochemical performance of the anode obtained from full cell testing and analysed via iV-curves and impedance spectroscopy.

A1008

Sulphur Poisoning of Anode-Supported SOFCs under Reformate Operation

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Abstract

The impact of sulphur-poisoning on catalysis and electrochemistry of anode-supported solid oxide fuel cells is analyzed via electrochemical impedance spectroscopy. Different types of anode supported cells are operated in hydrogen/steam- as well as simulated reformate- (H_2+H_2O+CO+CO_2+N_2) fuels containing 0.1 to 15 ppm of H_2S.
A detailed analysis of impedance spectra by the distribution of relaxation times (DRT) and a subsequent Complex Nonlinear Least Squares (CLNS) fit separates the impedance changes taking place at the anode and the cathode. Two main features were detected in the DRT, a decreased reaction rate of the electrochemical hydrogen oxidation and a deactivation of the catalytic conversion of CO via the water-gas shift reaction.
During the first exposure of the cell to a H_2S-containing fuel, an enhanced degradation is observed. The degradation rate increases several hours after H_2S was added to the fuel and decreases after the poisoning is completed. The polarization resistance increased by a factor of 2 to 10, depending on H_2S-content, fuel composition and cell type.
Comparing the temporal characteristics of the polarization resistance of two different anode supported cells, it could be shown that the accumulated H_2S-amount divided by the Ni-surface area inside the anode substrate and anode functional layer determine the onset of the degradation.

A1009

Degradation of a High Performance Cathode by Cr-Poisoning at OCV-Conditions

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Abstract

The performance and the long-term stability of solid oxide fuel cells (SOFC) at single-cell level have been continuously improved over the past 10 years. But whenever the individual cells are connected by a metallic interconnector (MIC) and no Cr-retention layers are applied, the stack performance undergoes a pronounced degradation. Possible cause, among others, is the effect of Cr-evaporation from the MIC and Cr-poisoning of the cathode.
In this work we investigate the effect of Cr-poisoning by means of impedance spectroscopy at OCV-condition. The anode-supported cell is operated in Cr-free environment for the first 70h of the cell test at 800 °C supplying air to the cathode and a varying mixture of H_2O/H_2 to the anode. The performance of the cell is determined by current-voltage (CV) measurement after the start up. After an operating time of 70 h in the absence of chromium species a Cr-source was switched on by passing the oxidant (air) through a Crofer22APU powder bed. In order to determine the degradation caused by Cr-poisoning electrical impedance spectra are collected at every 29 h of operating time. After further 275 h at OCV-condition in the presence of Cr-source another CV-curve is measured.
A detailed analysis of the impedance spectra by the distribution of relaxation times (DRT) enables a separation of the cathode polarization resistance. During the Cr-free operation the cathode polarization shows a constant value. After the Cr-source is switched on a strong increase of the cathode polarization resistance is observed. This unique result shows clearly that Cr-poisoning of a LSM/8YSZ-cathode already takes place at OCV-condition.

A1010

Evaluation of the chemical and electrochemical effect of biogas main components and impurities on SOFC: first results

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Abstract

Pile-Eau-Biogaz is a project, which examines the impact of biogas fuels on the performance of the SOFC. This three-years project was initiated in January 2011 and is jointly conducted by SUEZ ENVIRONNEMENT, GDF SUEZ, CEA, LEPMI-Grenoble and INSA-Lyon, supervised by the ANR, the French Research National Agency (ANR) through its Hydrogen and Fuel Cells program.

The main goal of this project is to operate a SOFC stack fuelled with real biogas in a wastewater treatment plant. To prepare this demonstration, experiments are planned to investigate SOFC operations under various simulated biogases with different carbon (from hydrocarbon fuel) to CO_2 and H_2O ratios. The performance and durability of both anode- and electrolyte-supported cells will be investigated depending on these parameters. In addition, the individual impact of the following specifies representing biogas major impurities- H_2S, HCl and siloxanes, will be examined.
Currently, the first simulated biogas-fuel tests are performed on the cells. Both anode and electrolyte-supported cells are investigated at 800 °C under a current density of 0.3 A/cm². Experiments are also conducted to evaluate the chemical reactions of the selected pollutants with electrode materials. In next few months, the impact of impurities will be tested on both types of cells. All together, these experiments will provide a new insight into the potential and limitations of SOFC fuelled with biogas.

A1011

Study of Fuel Utilization on Anode Supported Single Chamber Fuel Cell

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Abstract

Single Chamber Solid Oxide Fuel Cells (SC-SOFC) show a growing interest and are the concern of more and more papers. In such device, anode and cathode are exposed to a gas mixture of fuel (hydrocarbon, mainly CH_4) and oxidant (air) so that no more sealing with electrolyte is necessary contrary to conventional Solid Oxide Fuel Cell. Their operating principle is based on the different catalytic activities of anode and cathode. Ideally, the anode has to be active for the partial oxidation of fuel producing hydrogen and then for the electrochemical oxidation of hydrogen, while the cathode should present only a strong electro-catalytic activity for oxygen electrochemical reduction. This new configuration offers a direct hydrocarbon reforming on the anode performed thanks to the partial oxidation of fuel. Furthermore, this exothermic reaction allows reducing the working temperature of the cell. The geometry of Single Chamber Fuel Cell is also more flexible and allows innovative configurations. At this time, the best performances are obtained for anode-supported cell with a maximum power density of 1500mW.cm^{-2}. This result is encouraging for SC-SOFC development and optimization. The main challenge for SC-SOFC is to improve the fuel utilization with a highest reported value of 11%.
In this work, anode-supported fuel cells prepared with NiO/CGO anode pellets, screen-printed $Ce_{0.9}Gd_{0.1}O_{1.95}$ (CGO) electrolytes, and a cathode composed of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$/CGO (LSCF/CGO 70/30) were investigated under several methane/oxygen/nitrogen atmospheres. The study of anode reduction by TGA at 700°C shows a carbon deposition under diluted methane but a successful reduction was obtained after an initialization under diluted methane followed by a final treatment under methane-to-oxygen ratio (R_{mix}) of 2. Optimization of anode-supported fuel cell was investigated regarding the working temperature, R_{mix} and the electrolyte microstructure on two cells. The Open Circuit Voltage (OCV), the power density and the fuel utilization increased when R_{mix} and temperature decreased. The electrolytes of both cells have a porous microstructure and the electrolyte of the second cell, with the highest thickness, bring better performances. At 600°C for R_{mix}=0.6, the maximum power density is improved from 60 to 160mW.cm^{-2}. Comparing the fuel utilization, it increases from 3% for the 1st cell to 6% for the 2nd cell for the same testing conditions.

A1012

Anode-supported single-chamber SOFC for energy production from exhaust gases

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Abstract

Solid oxide fuel cells working in a mixed gas atmosphere (fuel and oxidant), the so-called single chamber SOFCs (SC-SOFCs), have been increasingly studied in the past few years. The absence of sealing between the two compartments provides an easier operation than a classical “two-chambers” SOFC. Operating principle of SC-SOFCs lies on a difference in catalytic activities of both electrodes, which requires improved selectivity of anode and cathode materials to fuel oxidation and oxygen reduction, respectively. Hydrogen-air mixtures are not commonly used under single chamber conditions because of their high reactivity and risk of explosion. Therefore, hydrocarbons are preferentially used as fuel.
In this study, SOFCs in a single chamber configuration are investigated as devices for electricity production through gas recycling from an engine exit. Cells would be embedded at the exit of the engine and convert hydrocarbons unburned by combustion into electricity. This forward-looking energy recovery system could be applicable to automotive vehicles as well as to plants. Hibino *et al.* in 2008 [1-2] demonstrated the feasibility of such a device with stack of 12 SC-SOFCs incorporated at the exit of a scooter engine. However power output was not as high as expected. Optimization of the system including architecture, gas mixture and materials modification may lead to enhanced performances.
Our project is focused on anode-supported cells working in a mixture of hydrocarbons (propane and propene), oxygen, carbon monoxide, carbon dioxide, hydrogen and water corresponding to the composition of exhaust gas after the first oxidation catalyst. GDC ($Ce_{0.9}Gd_{0.1}O_{1.95}$) was chosen as electrolyte because of its high ionic conductivity at temperatures corresponding to the ones of exhaust gases. Concerning cathode, a screening of four materials has been made, some well-known materials through literature [3-4] and leading to highest performances such as LSCF($La_{0,6}Sr_{0.4}Co_{0,2}Fe_{0,8}O_{3-\delta}$), SSC($Sm_{0.5}Sr_{0.5}CoO_3$) and BSCF($Ba_{0,5}Sr_{0.5}Co_{0,8}Fe_{0,2}O_{3-\delta}$), and one only investigated in “two-chambers” SOFCs: $Pr_2NiO_{4+\delta}$ (PNO) [5]. A preliminary study concerning cathode materials has been conducted. Stability tests during five hours and catalytic activity studies in the gas mixture were performed on the raw materials and allowed to make a first choice among cathodes. Two ratios hydrocarbons/oxygen (R) were used for materials testing considering their stability at high temperature: R=0.21 and R=0.44. LSCF and $Pr_2NiO_{4+\delta}$ were proven to be the most stable cathode materials and LSCF demonstrated a lower catalytic activity towards hydrocarbon partial oxidation than $Pr_2NiO_{4+\delta}$ especially for a R=0.44 ratio. LSCF can thus be considered as a better cathode material than $Pr_2NiO_{4+\delta}$.

A1013

Electrochemical Performance and Carbon-Tolerance of $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_3$ – $Ce_{0.9}Gd_{0.1}O_{1.95}$ Composite Anode for Solid Oxide Fuel Cells (SOFCs)

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Abstract

Solid oxide fuel cells (SOFCs) with all-ceramic anodes have gained considerable interest because they offer attractive features such as resistance to coking, reduction-oxidation (redox) stability, and tolerance to sulfur. In this work, the $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_3$ (LSCM) - $Ce_{0.9}Gd_{0.1}O_{1.95}$ (GDC) composite was evaluated for potential use as the ceramic SOFC anode. The LSCM-GDC composite powder was synthesized by particle-dispersed glycine-nitrate process (GNP). The crystal structure, phase purity, and chemical stability of the composite powder under the processing and operating conditions were verified using X-ray diffraction (XRD) analysis. The electrode performance was characterized by impedance analysis on symmetric cells under hydrogen and methane environments. The electrolyte-supported cells with YSZ electrolyte and $(La_{0.7}Sr_{0.3})_{0.95}MnO_3$ (LSM) / YSZ composite cathode were fabricated, and the performance was evaluated at 700~850°C with humidified H_2 and CH_4 as fuel and air as oxidant. The infiltration effect of the nano-scale ruthenium catalysts on the performance of the ceramic anode was investigated under various operating conditions.

A1014

Chromium Poisoning Mechanism of $(La_{0.6}Sr_{0.4})(Co_{0.2}Fe_{0.8})O_3$ Cathode

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Abstract

Chromium (Cr) poisoning and distribution of deposited Cr in the (La0.6Sr0.4)(Co0.2Fe0.8)O3 (LSCF) cathode under Cr containing vapors flow was investigated. For accelerating Cr deposition in the LSCF cathode, humidified air (Cr containing vapor species) was supplied to the cathode. The degradation behavior of the LSCF cathode was monitored as a function of time. Under the cathode polarization of -200 mV, cathode currents decreased by the deposition and reaction of Cr with LSCF. A significant increase of the polarization resistance (low frequency contribution) was observed by the supply of Cr from the AC impedance. Polarization resistance increase can be ascribed to the increase of resistance associated with a slow relaxation process such as oxygen adsorption (Oad) on the LSCF cathode. Under the OCV condition, the porous LSCF cathode was infiltrated by Cr and Sr compounds. On the other hand, large amounts of SrCrO4 were formed at cathode surface/Pt-mesh current collector interface than within the cathode under polarization condition. The difference of SrCrO4 formation is due to the diffusion of Sr to the surface of porous LSCF cathode during the DC polarization.

A1015

Cell testing: challenges and solutions

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Abstract

Energy conversion based on SOFC technology has made significant progress in the last few years. The MEA (membrane electrolyte assembly) is a key component of SOFC modules used as an electricity and heat power plant with high electrical efficiency. For research and development of planar SOFC a detailed knowledge of individual material behavior such as long-term stability, electrochemical performance, degradation rates, durability for reduction/oxidation as well as thermal cycles and performances in different gas compositions is required. In consideration of such comprehensive cell characterization an optimal measurement environment need to be provided. Cell housings have to be high-temperature-qualified up to 1000°C, chemically inert and reduction- /oxidation resistant. Furthermore, the housing should provide lossless gas-supply and a non-destructive mechanical compression. In order to fulfill these requirements Fraunhofer IKTS in close collaboration with FuelCon developed a ceramic housing for cell characterization at SOFC operating conditions. The housing offers possibility of measurement for three different cell types (ESC, ASC and MSC). For an individual characterization of single cell a standard measurement procedure has been developed, which allows comparability of SOFC related characteristics independently from cell type. This paper will give an overview of test results obtained on electrolyte supported cells on basis of 3YSZ electrolyte.

A1101

High Temperature Co-electrolysis of Steam and CO_2 in an SOC stack: Performance and Durability

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Abstract

High temperature electrolysis based on solid oxide electrolysis cells (SOECs) is a very promising technology for energy storage or production of synthetic fuels. By electrolysis of steam, the SOEC provides an efficient way of producing high purity hydrogen and oxygen [1]. Furthermore, the SOEC units can be used for co-electrolysis of steam and CO_2 to produce synthesis gas ($CO+H_2$), which can be further processed to a variety of synthetic fuels such as methane, methanol or DME [2].

Previously we have shown at stack level that Ni/YSZ electrode supported SOEC cells can be operated at 850 ^oC and -0.5 A/cm^2 with no long term degradation, as long as the inlet gases to the Ni/YSZ electrode were cleaned [3]. In this work, co-electrolysis of steam and carbon dioxide was studied in a TOFC® 10-cell stack, containing 3 different types of Ni/YSZ electrode supported cells with a footprint of 12X12 cm^2. The stack was operated at 800 ^oC and -0.75 A/cm^2 with 60% conversion for a period of 1000 hours. One type of the cells showed no long term degradation but actually activation during the entire electrolysis period, while the other two types degraded. The performance and durability of the different cell types is discussed with respect to cell material composition and microstructure. The results of this study show that long term electrolysis is feasible without notable degradation also at lower temperature (800 ^oC) and higher current density (-0.75 A/cm^2).

A1102

4 kW Test of Solid Oxide Electrolysis Stacks with Advanced Electrode-Supported Cells

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Abstract

A new test stand has been developed at the Idaho National Laboratory for multi-kW testing of solid oxide electrolysis stacks. This test stand will initially be operated at the 4 KW scale. The 4 kW tests will include two 60-cell stacks operating in parallel in a single hot zone. The stacks are internally manifolded with an inverted-U flow pattern and an active area of 100 cm^2 per cell. Process gases to and from the two stacks are distributed from common inlet/outlet tubing using a custom base manifold unit that also serves as the bottom current collector plate. The solid oxide cells incorporate a negative-electrode-supported multi-layer design with nickel-zirconia cermet negative electrodes, thin-film yttria-stabilized zirconia electrolytes, and multi-layer lanthanum ferrite-based positive electrodes. Treated metallic interconnects with integral flow channels separate the cells and electrode gases. Sealing is accomplished with compliant mica-glass seals. A spring-loaded test fixture is used for mechanical stack compression. Due to the power level and the large number of cells in the hot zone, process gas flow rates are high and heat recuperation is required to preheat the cold inlet gases upstream of the furnace. Heat recuperation is achieved by means of two inconel tube-in-tube counter-flow heat exchangers. A current density of 0.3 A/cm^2 will be used for these tests, resulting in a hydrogen production rate of 25 NL/min. Inlet steam flow rates will be set to achieve a steam utilization value of 50%. The 4 kW test will be performed for a minimum duration of 1000 hours in order to document the long-term durability of the stacks. Details of the test apparatus and initial results will be provided.

A1103

Enhanced Performance and Durability of a High Temperature Steam Electrolysis stack

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Abstract

High Temperature Steam Electrolysis (HTSE) is one of the most promising ways for hydrogen mass production. If coupled to a CO_2-free electricity and low cost heat sources, this process is liable to a high efficiency. High levels of performance and durability, in association with cost-effective stack and system components are the key points.
Former studies have highlighted that it was possible to reach performance as high as -1 A/cm² at 1.3 V at 800°C at the stack level [1]. However, the degradation rate obtained was around 8%/1000h, without any protective coatings on the interconnects [1]. The present study describes recent promising results obtained in terms of performance and durability at the SRU or stack level, thanks to the use of protective coatings on one hand, and of advanced cells on the other hand.
As expected, it has been demonstrated that the integration of protective coatings was mandatory to decrease the degradation rate, and that with optimized coatings, $(CoMn)_3O_4$ in the present case, it was possible to achieve the same durability as the one of the single cell tested in a ceramic housing. The type of cell was also shown to play a major role in the degradation rate. With advanced electrolyte supported cells, degradation as low as 1.6%/kh was obtained at 800°C for a current density of - 0.4 A/cm². With an advanced electrode supported cell, it has even been possible to reach a performance of - 1.1 A/cm² at 1.3 V at only 700°C. A durability test has been carried out at 700°C, with a degradation rate of 1.8%/kh at - 0.5 A/cm². In both cases, the higher is the current density, the higher is the degradation rate, with a mostly reversible effect. These degradation rates are much closer to the objectives, even if a bit higher than in SOFC mode.
Three complete thermal cycles have been successfully performed. Two types of electrical load cycles have also been performed, either slow or fast, from the OCV to the thermoneutral voltage of 1.3 V. The results showed that the HTSE stack can cycle very rapidly, and that the cycles considered do not induce any degradation. This makes HTSE a candidate to produce hydrogen as a mean to store renewable intermittent energies.
Finally a low-weight stack has been designed, keeping the advantages of the high performing and robust stack previously validated in terms of performance, durability and cyclability, but aiming at reducing the cost by the use of thin interconnects. An electrochemical performance as high as the one of the robust stack has been obtained, with degradation rates below 3%/1000h for a 3-cell stack. The thermal cyclability of this stack has also been demonstrated with one thermal cycle. Therefore it can be concluded that these results makes HTSE technology getting closer to the objectives of performance, durability, thermal and electrical cyclability and cost.

A1104

Electrolysis and Co-electrolysis performance of a SOEC short stack

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Abstract

In this study, a short SOEC stack (6-cells) was characterized both for electrolysis and co-electrolysis. In the former case, the stack was fed with a 90% steam, 10% hydrogen mixture and characterized between 600 and 700°C. An average cell voltage of 1.6V was reached at 1 Acm^{-2} and 700°C, corresponding to 60% steam conversion. However, a strong increase of the stack temperature (+25°C in average) was observed due to internal losses. Therefore, slow temperature scans were performed at fixed current to establish U-i-T maps and reconstruct isothermal U-i characteristics. The resulting U-i curves show reduced performance (e.g. 1.7V at 1Acm^{-2}, 700°C) but more realistic trends.
The stack was further polarized around the thermoneutral voltage (1.35V) at 0.26Acm^{-2}, 50% steam conversion and 650°C for 1160 hours. The different cell degradation rates ranged from +0.4 to +5.1%kh^{-1}. Shorter steady-state polarization sequences were also performed at 750 and 800°C.
Co-electrolysis was also performed between 750 and 850°C by feeding the stack with a 60% H_2O, 30% CO_2 and 10% H_2 mixture. 95% conversion was reached and the outlet syngas composition was close to that predicted by thermodynamics. Steam electrolysis tests were also carried on in the same conditions for comparison. The stack performance in the co-electrolysis mode was slightly lower than in the electrolysis mode.

A1105

SOEC enabled Methanol Synthesis

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Abstract

Solid Oxide Electrolyser Cell stacks (SOEC) are able to produce inert free synthesis gas of any desired composition from electric power, carbon dioxide and steam, but the necessary stack area, power and required balance of plant components will vary as function of conversion and gas composition. It is also important to avoid carbon formation [1].

Synthesis of methanol is deceptively simple, but in fact highly complex, because the equlibria, kinetics, selectivity and indeed the morphology of the synthesis catalyst itself changes as the synthesis gas composition changes [2,3].

The overall optimum plant configuration is thus a trade off between many different optimization criteria including degradation phenomena.

The paper will also consider and give examples of the possible synergies between SOEC plants and generation of synthesis gas from biomass gasification for the synthesis of methanol.

A1106

Direct and Reversible Solid Oxide Fuel Cell Energy Systems

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Abstract

Future energy systems are expected to be compatible with the environment (compatibility) to support constraints on CO_2 and other emissions. Other desired characteristics include flexibility (in using energy resources), capability (useful for different functions), adaptability (in meeting local energy needs, suitable for a variety of applications) and affordability (competitive in costs). Fuel flexible, direct and reversible solid oxide fuel cells (DR-SOFCs) can be a base technology for such systems. A DR-SOFC can generate electricity directly from a variety of fuels and can produce chemicals when integrated with an energy source. A DR-SOFC incorporating innovative designs and advanced materials has the potential for low cost, extraordinarily high power density, efficient direct conversion of any type of fuel, and long life. This paper discusses technological status, system concept and technology roadmap in the development of DR-SOFC energy systems for practical applications.

A1107

Advanced Electrolysers for Hydrogen Production with Renewable Energy Sources

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Abstract

The 3-year FCH project ADEL (ADvanced ELectrolyser for Hydrogen Production with Renewable Energy Sources) targets the development of cost-competitive, high energy efficient and sustainable hydrogen production based on renewable energy sources. A particular emphasis is given to the coupling flexibility with various available heat sources, allowing addressing both centralized and de-centralized hydrogen production market.
The ADEL 3-year-project target is to develop a new steam electrolyser concept, the Intermediate Temperature Steam Electrolysis (ITSE) aiming at optimizing the electrolyser life time by decreasing its operating temperature while maintaining satisfactory performance level and high energy efficiency at the level of the complete system, composed by the heat and power source and the electrolyser unit.
The project is built on a two scales parallel approach:

- At the stack level, the adaptation and improvement of current most innovative cells, interconnect/coating and sealing components for ITSE operation conditions aims at increasing the electrolyser lifetime by decreasing its degradation rate
- At the system level, to facilitate an exhaustive and quantified analysis of the integration of this “new generation ITSE” with different heat and power sources like wind, solar, geothermal and nuclear, flow sheets will be produced with adjustable parameters.

The paper presents data on electrochemical performance of specifically developed materials for electrolysis in a temperature range around 700°C. Conclusions of an international workshop are presented on where and under what conditions ITSE systems can contribute to the new, low-carbon energy system.

A1108

Pressurized Testing of Solid Oxide Electrolysis Stacks with Advanced Electrode-Supported Cells

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Abstract

A new facility has been developed at the Idaho National Laboratory for pressurized testing of solid oxide electrolysis stacks. Pressurized operation is envisioned for large-scale hydrogen production plants, yielding higher overall efficiencies when the hydrogen product is to be delivered at elevated pressure for tank storage or pipelines. Pressurized operation also supports higher mass flow rates of the process gases with smaller components. The test stand can accommodate cell dimensions up to 8.5 cm x 8.5 cm and stacks of up to 25 cells. The pressure boundary for these tests is a water-cooled spool-piece pressure vessel designed for operation up to 5 MPa. The stack is internally manifolded and operates in cross-flow with an inverted-U flow pattern. Feed-throughs for gas inlets/outlets, power, and instrumentation are all located in the bottom flange. The entire spool piece, with the exception of the bottom flange, can be lifted to allow access to the internal furnace and test fixture. Lifting is accomplished with a motorized threaded drive mechanism attached to a rigid structural frame. Stack mechanical compression is accomplished using springs that are located inside of the pressure boundary, but outside of the hot zone. Initial stack heatup and performance characterization occurs at ambient pressure followed by lowering and sealing of the pressure vessel and subsequent pressurization. Pressure equalization between the anode and cathode sides of the cells and the stack surroundings is ensured by combining all of the process gases downstream of the stack. Steady pressure is maintained by means of a backpressure regulator and a digital pressure controller. A full description of the pressurized test apparatus is provided in this paper.

A1109

Modeling and Design of a Novel Solid Oxide Flow Battery System for Grid-Energy Storage

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Abstract

Viable electric energy storage (EES) solutions are recognized as an important area of development for the energy grid of the future. A solid oxide flow battery (SOFB) concept utilizing a reversible ceramic based solid oxide cell (SOC) stack as the working component is proposed for EES applications. The SOFB system converts electricity to chemical energy (charges) by electrolyzing H_2O and CO_2 feed gases into a fuel-rich mixture of H_2, CO, CH_4 which is stored for later use. The SOFB discharges in fuel cell mode by converting the chemical energy of the stored fuel mixture back into electricity through electrochemical oxidation. A thermodynamic system level model is presented, including balance of plant components (compressors, heat exchangers, and storage tanks), to assess system design concepts and overall SOFB performance. It is shown that increasing the stack operating pressure and nominal cell temperature increase roundtrip efficiency. With the SOFB cell-stack operating at 20 bar, 750°C, and an economically favorable fuel cell power density of 0.37 W/cm^2, the model predicts a roundtrip efficiency of almost 66%. The roundtrip efficiency is improved to nearly 75% when the area specific resistance (ASR) is lowered to 0.20 Ω-cm^2, while maintaining a high power density (0.39 W/cm^2).

A1201

Chemical Degradation of SOFCs: External impurity poisoning and internal diffusion-related phenomena

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Abstract

Durability of SOFCs is one of the most important requirements for their commercialization. In this paper, we analyze chemical degradation phenomena caused by both extrinsic and intrinsic origins. As external degradation, impurity (sulfur, phosphorus, boron etc.) poisoning has been systematically analyzed and classified. Such impurities could be introduced from practical fuels, system components, as well as inexpensive raw materials. In addition, we present typical intrinsic chemical degradation phenomena observed, mainly diffusion-related processes (interdiffusion, grain boundary diffusion, dopant dissolution, phase transformation etc.), around interfaces between the electrolyte and the electrode, which has been revealed through high-resolution STEM-EDX (Scanning Transmission Electron Microscope - Energy-Dispersive X-ray analyzer) analysis of cells after long-term tests. Importance of academia-industry collaborations is discussed.

A1202

Effect of pressure variation on power density and efficiency of solid oxide fuel cells

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Abstract

Hybrid power plants consisting of SOFC and gas turbine promise high electrical efficiencies. The German Aerospace Center (DLR) aims at building a hybrid power plant with a SOFC that is operated at elevated pressure. To ensure a stable operation of the power plant, the operating characteristics of SOFC at various conditions have to be known. Pressure related effects are of particular interest as they are so far not thoroughly researched.

Experiments with a SOFC stack made of planar anode-supported cells were carried out at a temperature of 1073 K using an anode gas mixture of 30% hydrogen and 70% nitrogen. Pressure was varied between 1.35 and 8 bar. Fuel utilization was kept constant at 50%. All points of polarization curves were measured at steady state. Analyses were carried out with a focus on the influence of pressure variation on power density and efficiency.

Results show that SOFC performance is improved with increasing pressure. Power density increases significantly if efficiency is kept constant. Increases up to 100% were measured. On the other hand, electrical efficiency can be enhanced if power density is kept constant. Here, an increase of up to 14% was measured. Pressure effects show logarithmic behavior for all operating conditions with decreasing influence towards higher pressure.

A1203

CFY-Stack: from electrolyte supported cells to high efficiency SOFC stacks

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Abstract

The stack concept with electrolyte supported cells (ESC) has the highest potential for realization of robust SOFC stacks. However, to achieve high power density and efficiency comparable to anode supported cell (ASC) stacks, a high ionic conducting electrolyte on basis of fully scandia stabilized zirconia should be used. The utilization of this electrolyte is only possible with TEC (thermal expansion coefficient) adjusted metallic CFY interconnects. To achieve robust SOFC stacks, all components have to be optimized to withstand high temperature corrosion, temperature cycling and repetitive reduction / oxidation (RedOx cycles) on the fuel side of the stack. Tests on material and interface level have been developed and applied on different scales to prove the long-term stability and cyclability of the stack components. Optimizing materials and material combinations, the long-term power degradation has been reduced from 3 % / 1.000h to <1,5 % / 1.000h. Power losses of <0,5% per 20 cycles during thermal cycling have been achieved as well. The most challenging issue is RedOx cycling of the stack; a special RedOx procedure was set to compare different material combinations in the stack. The current stack can withstand up to 25 full RedOx cycles with a power degradation of 3-8%. A system relevant RedOx procedure for stacks shows lower degradation in comparison to full RedOx cycles. This showes that in the stack the cyclability of electrolyte supported cells can be efficiently supported by system related issues.

A1204

Development of Robust and Durable SOFC Stacks

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Abstract

Topsoe Fuel Cell is developing stacks designed for APU applications based on diesel reformate as well as stacks designed for CHP applications based on steam-reformed natural gas. Significant differences between requirements to access these markets are evident. However, it is also evident that stacks for both applications must be able to endure load cycles, temperature cycles and the concurrent dynamic mechanical stress-profiles.

Topsoe Fuel Cell focuses on understanding the influence of dynamic operation on stack performance. A compressed test, designed to reveal robustness related issues in a stack, has been used in the development of two new stack designs. Such a test must be able to reveal e.g. cell fracture, loss of electrical contact between interconnect and cell, de-lamination within a cell or de-lamination between sealing and cell. The test is made by inducing stress profiles to the stack relevant for the specific applications or even harsher.

The present development towards robust and durable stacks is based on materials and components with low degradation rates as proven by operation for more than 10000 hours in previous stack designs. The development work has thus focused on design and process optimization in order to obtain significantly more robust stacks.

This paper is a presentation of the developed stacks and a discussion of the results obtained from testing two pre-production series of the developed stacks.

A1205

Long-term Testing of SOFC Stacks at Forschungszentrum Jülich

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Abstract

Forschungszentrum Jülich is performing long-term SOFC stack tests for more than 17 years. In the beginning 1,000 operating hours were already considered long-term testing. Within the European project Real-SOFC (2004-2008) test durations were prolonged up to 5,000 hours. Towards the end of the project durability tests operating at 700 °C were started with two short stacks using improved protecting layers on the air side of the ferritic steel interconnects and cells with LSCF cathodes. Both stacks reached the first milestone of 10,000 hours in November 2008. The operation of one stack, clearly showing progressive degradation over the last 5,000 hours, was terminated after more than two years for inspection of the status of the components and interfaces. The second stack is now in operation for more than 4 years having reached 40,000 hours beginning of March 2012. The average voltage degradation over the full duration was about 1% per 1000 hours. Another short stack with plasma sprayed protective coatings on the air side of the interconnects is running for more than 11,000 hours, showing less than 0.15% voltage degradation per 1000 hours. A stack with a similar configuration but LSM cathodes operated at a temperature of 800 °C broke down after two years. The reason for the break-down could be determined by post-test analysis. In the meantime a 2.5 kW stack is in operation on internally reformed methane for 3,000 hours aiming at 5,000 hours of operation.

A1206

Study on Durability of Flattened Tubular Segmented-in-Series Type SOFC Stacks

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Abstract

Although residential SOFC systems were successfully introduced into the Japanese market for the first time in the world, low-cost and durable SOFC stacks would be required in order to realize widespread utilization of the SOFC systems. We have developed the flattened tubular segmented-in-series type SOFC stacks which could have advantages of low cost and high durability. The durability was studied in a project managed by the New Energy and Industrial Technology Development Organization (NEDO) and in the Tokyo Gas Co., Ltd. The continuous durability tests of the stacks were carried out for 5000 h. The initial degradation had a tendency to decrease with time, and the degradation rate from 4000 h to 5000 h was 0.26%/kh (average of 2 samples) at a constant operational temperature (775 ºC). It was almost the same level to the project's target (0.25%/kh). The continuous durability test at high temperature showed that the degradation rate from 4000 h to 5000 h was 0.24%/kh at 800 ºC and 0.31%/kh at 825 ºC, respectively. We considered that no use of alloy as the component was one of the reasons why they showed low degradation up to 825 ºC. Each component of the stack was analyzed through multidisciplinary studies in the NEDO project to minimize degradation. The effect of thermal cycle and redox cycle on the degradation was also studied. The degradation after 100 times of thermal cycles was shown to be 0.008%/cycle for the stack after 2000 h continuous operation. Redox cycle of the cells was carried out three times, but no damage was observed. While shutdown tests were repeated 100 times, the stack showed low degradation and could generate as usual. One of the reasons why the stack had high durability over redox cycle was considered to have structurally thin anode. Poisoning of anode of the stack was studied. The degradation tendency of the stack was similar to a standard cell, and remarkable difference in each cell of the stack could not be found even if fuel concentration in the cells differs considerably. Because of the potential for low cost and high durability, we considered the stack could become a candidate for large-scale SOFC commericializations. In order to accelerate such development, further multidisciplinary efforts would be desired.

A1207

SOFC Module for Experimental Studies

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Abstract

The basic features of the 100 to 200 Watt SOFC Module have been presented at the European Fuel Cell Forum events of 2010 and 2011. Stacks are composed of anode-supported cells and bipolar plates of 60 mm x 60 mm footprint. The bipolar plates are fitted with electric heating elements. Operating temperatures of 600°C are obtained in a few minutes. At temperatures above 800°C each cell delivers about 10 Watts of power. Conversion efficiency is high resulting from high fuel utilization and good thermal design.

As no furnace and high temperature feed-throughs are needed to operate the module, universities, research labs and industrial developers of fuel cells have shown much interest in the innovative design. Many of them have experimented with low temperature fuel cells, but now discover the potentials of the solid oxide fuel cells for power production from hydrocarbon fuels. Therefore, the module has been modified to provide attractive options for demonstrations of the technology and a wide range of investigations in university laboratories. The improvements include an optimization of the anode and cathode flow field design. Supply and exhaust tubes are now placed diagonally opposed resulting in a better distribution of conversion rates over the active cell area. Furthermore, the vertical air and fuel supply and exhaust tubes are now open on both ends. The gaseous media can be supplied from the top and/or from the bottom. Also, the exhaust can be directed up or down, or in both directions if so desired. Furthermore, thermocouples can be inserted into the stack for onsite monitoring of the gas temperatures during operation. Similarly, gas probes can be drawn from inside the stack in the vicinity of the electrochemical process for external gas composition analysis.

The SOFC modules are also used by developers of systems to demonstrate innovative designs of portable, mobile or stationary fuel cell equipment. The original idea of a providing a universal SOFC solutions for many applications appears to find widespread acceptance.

A1208

Post-Test Characterisation of SOFC Short-Stack after 19000 Hours Operation

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Abstract

The long term reliable operation of stack with a low degradation rate is a prerequisite for the commercialization of solid oxide fuel cells (SOFCs). A SOFC short stack of F-design was characterized after long-term operation of 19 000 h at 800 °C under a current load of 0.5 A/cm². The stack was shut down after failure of one cell and was subsequently partly embedded in resin and thereafter various stack parts were cut from multiple characteristic places of interest. All important components (cell, interconnect, sealant, and ceramic and metallic contacts) were characterized with respect to micro-structural or chemical changes or interactions with the adjacent components.
Although the post test characterization revealed less changes and interactions than expected, one clear feature was the Mn diffusion from the (La,Sr)MnO_3 cathode into the 8YSZ electrolyte that led to local Mn-enrichment at the grain boundaries, which probably created electronic pathways leading to a reduction of the electrolyte resistivity and weakening of the electrolyte layer resulting in grain boundary fracture that was the ultimate reason for the failure of the component. However, it can be concluded that by tailoring especially the cathode material and reducing the working temperature operation of SOFC stacks for an industrial relevant time frame appears to be possible.

A1209

Solid Oxide Fuel Cells under Thermal Cycling Conditions

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Abstract

Thermal cycling causes particularly challenging conditions for the operation of solid oxide fuel cells (SOFC). The number of start-up and shut-down procedures usually varies from a few to thousand. In the case of an auxiliary power unit (APU), as example for mobile applications, a high number of starting sequences are required. Beside this the APU system should be ready for operation in a very short time, so furthermore a quick start-up is necessary.

High temperature gradients and high thermal cycling rates have a negative impact on cell performance and lifetime. These conditions encourage the appearance of degradation mechanisms like delamination, crack formation or nickel agglomeration. Another damaging mechanism concerning start-up and shut-down phases is the so called redox cycle, a repeated oxidation and reduction of the anode.

Within this work planar anode supported cells were tested under different cycling conditions to investigate effects of start-up and shut-down operations. The test parameters such as heating rate or cycle number are similar to the operating conditions of an APU. In a first step pre-tests with a mixture of H_2 and N_2 were carried out. Next tests with synthetic diesel reformate are planned.

A test procedure consists of a cold start, several warm starts and a hot stand-by state. The maximum heating rate is about 16 K/min at an operating temperature of 650°C. At the end of each test cycle a current-voltage (i-V) characteristic was measured. The open circuit voltage (OCV) remained stable, whereas the cell voltage decreased.

A1210

500W-Class Solid Oxide Fuel Cell (SOFC) Stack Operating with CH_4 at 650°C Developed by Korea Institute of Science and Technology (KIST) and Ssangyong Materials

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Abstract

We demonstrated a 500W-class SOFC stack employing anode-supported planar cells, stainless steel-based metallic interconnects, and glass-filler composite sealants for intermediate-temperature operation (~650°C). The stack was composed of 24 cells with the area of 10 x 10 cm^2, and the single cells consisted of Ni - yttria-stabilized zirconia (YSZ) cermet anode, scandia-stabilized zirconia (ScSZ) electrolyte, gadolinia-doped ceria (GDC) interlayer, and Sr-doped lanthanum cobaltite (LSC) / GDC composite cathode. The stack exhibited the open circuit voltage close to the theoretical value at 650°C, which indicated the excellent sealing characteristics of the glass-filler composite system optimized for intermediate-temperature operation. It provided stable power output of over 500W with H_2 and CH_4 fuel at 650°C.

A1211

Influence Factors of Redox Performance of Anode-supported Solid Oxide Fuel Cells

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Abstract

Ni-based anode is the most commonly used anode material of solid oxide fuel cell (SOFC) due to its excellent catalytic activity and durable manufacture. However, its mechanical instability is a main drawback especially upon the redox cycles. Fuel supply interruption will lead to performance degradation. In this study, we focused on the redox stability of anode-supported SOFCs which produced by Ningbo Institute of Materials Engineering and Technology (NIMTE), Chinese Academy of Sciences (CAS). Several influence factors of redox performance of Ni-based anode supported SOFCs (ASCs) such as protecting ambiance, redox cycle period were studied. Fuel supply (hydrogen in this study) flow was shut off for different duration at 800℃ under different conditions to simulate the accidental fault of generating system. Open circuit voltage (OCV) was used to evaluate the reliability of the cells. It declined slightly and formed a platform during fuel shuting-off process and easily to recover to the initial lever in a short duration. When the process exceeded a critical duration (almost ≥4 hours), the OCV declined rapidly to 0 V and could not recover. The SEM and EDS results of the microstructure of the ASCs which have undergone redox cycles were also discussed.

A1212

Manufacturing and Testing of Anode-Supported Planar SOFC Stacks and Stack Bundles

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Abstract

To achieve high output performance of solid oxide fuel cells (SOFCs) and their commercialization, planar anode-supported SOFC stack modules were developed by Fuel Cell and Energy Technology Division at the Ningbo Institute of Material Technology and Engineering (NIMTE). A stack configuration with open gas flow channels at the air outlet was designed for NIMTE stack module. The stack module consists of 30 pieces of anode-supported single cells. More than one hundred stack modules have been manufactured by NIMTE since 2010. The open circuit voltage (OCV) was generally more than 33V, indicating that the stack module was sealed well. The maximum output power of the 30-cell stack module ranged from 300W to 868W, corresponding to output power density of 0.15~0.46Wcm^{-2} at the temperature of 800 ^{o}C. Durability of the stack module was also tested, and the results showed that the degradation rate reached 2.2%/1000h under 800 ^{o}C. Our previous investigation showed the output performance of the SOFC stack can be increased by improving the contact between the interconnect and the cathode current collecting layer. The degradation rate of short-stack was reduced to 1.35%/1000h by the aforementioned method. Two, four and eight stack modules were also integrated as stack bundles in NIMTE. The corresponding output power reached 700W, 1kW and 2.5 kW, respectively. The durability of stack module bundles was found to be affected by the temperature difference within the stack bundles and the quality of stack modules. Stack modules with high quality are being manufactured and experiments are being conducted to lower temperature difference within stack bundles to improve their durability.

A1213

Effects of Current Polarization on Stability and Performance Degradation of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$ Cathodes of Intermediate Temperature Solid Oxide Fuel Cells

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Abstract

The stability of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$ (LSCF) cathodes was investigated at a constant current density of 200mA cm^{-2} and 750°C in air. The mechanisms of performance degradation for impregnated LSCF cathodes were compared with screen-printed LSCF cathodes. The cathode polarization resistance (R_p) of LSCF impregnated YSZ (LSCF+YSZ) cathodes increased from 0.24Ω cm^2 to 0.4Ω cm^2 and the ohmic resistance (R_O) from 2.27Ω cm^2 to 2.74Ω cm^2 after current polarization at 200mA cm^{-2} for 24h, respectively; due to the damage of well-connected porous structure. In contrast, R_p of screen-printed LSCF cathodes had no significant change and R_O changed from 2.22Ω cm^2 to 3.18Ω cm^2 after current polarization at 200mA cm^{-2} for 24h. This indicates that LSCF+YSZ cathodes, which have high surface activity, are more instable than screen-printed LSCF cathodes. Performance degradation of LSCF+YSZ cathodes is mainly caused by the damage of well-connected porous structure and coalescence of LSCF particles. While less porosity and microstructure coarsening played a dominate role in performance degradation of screen-printed LSCF cathodes.

A1214

Fabrication and performance evaluation based on external gas manifold planar SOFC stack design

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Abstract

This study reports the development of planar-type solid oxide fuel cell (SOFC) stacks based on an external gas manifold and a metal foil interconnect design. Depending on the design, a 5-cell stack and a 10-cell stack with cell size of 10×10 mm^2 were established and tested, in which the short stack produced about hundreds of Watts in total power at 750 °C. The stack has been further investigated by performance degradation and thermal cycling tests. The test results have demonstrated that the stack design has excellent performance and reliability, which is ready for SOFC stack fabrication and assembly.

A1215

Interconnect cells tested in real working conditions to investigate structural materials of a stack for SOFC

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Abstract

A specific sample called “interconnect cell” made of common SOFC electrodes materials (i.e. Ni for the anode and LSCF for the cathode) placed on the two sides of an AISI 441 FSS disc with the edge covered by a glass sealing was prepared. This specimen was then tested at SOFC operating conditions using the “Real Life Tester” in order to check the evolution of each side in terms of ASR and EIS changes due by insulating phases formation. The characterization of the samples have been made after several hundred hours of ageing at 600°C in dual atmosphere (synthetic air at the cathode, 3% wet hydrogen at the anode), under a constant current load of 500mA/cm^2.
The investigation techniques applied “post mortem” on the samples (i.e. XRD, SEM-EDXS on surfaces and cross sections) offered a close insight on the behavior of all materials in a stack, except the electrolyte, without the need to assemble it.

A1216

Characterization of SOFC Stacks during Thermal Cycling

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Abstract

At the German Aerospace Center (DLR) SOFC short stacks and stacks are developed and tested in cooperation with several industrial and research partners. The present paper presents results of light weight SOFC short stacks and stacks in the ZeuS 3 project under stationary and dynamically operating conditions. The results focus on the electrochemical behavior of SOFC stacks during thermal cycling between 50°C and 750°C. The stacks with stamped metal sheet bipolar plate cassettes were fabricated by ElringKlinger AG. Ferritic steel of Crofer APU from ThyssenKrupp AG is used as bipolar plate material. ASC cells with either LSM or LSCF cathodes from Ceramtec GmbH are integrated in the stacks. The electrochemical characterization mainly consists of current-voltage measurements and electrochemical impedance spectroscopy (EIS). The stack characteristics, e.g. OCV, ASR and power density, are discussed as a function of thermo cycles. The results are compared to non-cycled stacks. In order to understand the degradation mechanisms the SOFC stacks were analyzed by electrochemical impedance spectroscopy. The resistances in the stacks were determined by fitting of the spectra with an equivalent circuit. The resistances in the stacks were determined by fitting of the spectra with an equivalent circuit. The voltage losses in the stacks were calculated by integration of the resistances over the current density. The stacks were post-examined by metallographic, microscopic and element analysis methods.

A1217

Experimental evaluation of the operating parameters impact on the performance of anode-supported solid oxide fuel cell

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Abstract

The issue of renewable energy is becoming significant due to increasing power demand, instability of the rising oil prices and environmental problems. Among the various renewable energy sources, solid oxide fuel cell is gaining more popularity due to their higher efficiency, cleanliness and fuel flexibility. The performance of solid oxide fuel cells (SOFCs) is affected by various polarization losses, namely, ohmic polarization, activation polarization and concentration polarization. Under given operating conditions, these polarization losses are largely dependent on cell materials, electrode microstructures, and cell geometric parameters. Solid oxide fuel cells (SOFC) with yttria-stabilized zirconia (YSZ) electrolyte, Ni–YSZ anode support, Ni–YSZ anode interlayer, strontium doped lanthanum manganate (LSM)–YSZ cathode interlayer, and LSM current collector, were fabricated. The effect of various parameters on cell performance was evaluated. The parameters investigated were: (1) YSZ electrolyte thickness, (2) fuel composition, (3) anode support thickness, and (4) anode support porosity, (5) time and temperature impact. The effect of these cell parameters on ohmic polarization and on cell performance was experimentally measured. Cell parameter study, a cell with optimized parameters was fabricated and tested. The corresponding maximum power density at 800 ◦C was ∼0.5 Wcm^{-2}.

A1218

Round Robin testing of SOFC button cells – towards a harmonized testing format

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Abstract

Following up from the European FP6 project FCTESQA, and attempting to increase the capacity for univocal characterization of SOFC components in Italy, ENEA, University of Perugia and SOFCpower are carrying out a joint experimental campaign for the testing of button cells, short stacks and modules in their respective laboratories. These tests are carried out on material supplied by SOFCpower and have the duplicate objective of validating the different test environments as well as confronting the company's test procedures with those proposed in the FCTESQA project. In this way it is hoped to generate a Virtual Laboratory network that can provide the necessary testing hours required for full characterization of potentially commercially mature cell components and materials.
First tests were carried out on button cells, focusing on measurement of performance. Round robin testing of endurance and sulphur tolerance will follow. The outcome is proving satisfactory, but several initial practical difficulties had to be overcome for the establishment of repeatability of measurements. This also underlines the inadequate level of quality assurance as of yet in terms of *test facility* manufacture, which relies still chiefly on craftsmanship, reflecting to some extent the lack of industrialized production for SOFC end products.
Particular attention has been dedicated to the harmonization of results reporting to maximize the ease of interpretation of each laboratory's measurements. Test procedures and reporting formats are being implemented in several projects wherein the three laboratories are involved.

A1301

Coupling and thermal integration of a solid oxide fuel cell with a magnesium hydride tank

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Abstract

Some of the problems limiting the widespread diffusion of RES (Renewable Energy Sources) in a complex energy system are well known: (1) reliability; (2) low energy density; (3) especially, "flow" energy in place of "bulk" energy. All these points are strictly linked to a topic : the storage of the RES, both in space and in time domain. One interesting option for fast and clean storage of large amounts of RES could be represented by hydrogen. Hydrogen is the fuel with the highest energy content on a mass basis, but it has a very low energy content on a volume basis: among other systems, storage in solid matrix is interesting for future applications due to high energy density and safety issues.
A possibility of efficient use of RES-based hydrogen can be considered: a SOFC-based CHP system in the power range 1 kWe fed by pure hydrogen stored in a MgH_2 thank thermally integrated with the SOFC. The idea is to develop a smart system to provide electrical power and heat based on a high efficiency generator (SOFC electric efficiency higher than 60% and global efficiency around 80%) and a clean and sustainable electrochemically-optimised fuel (hydrogen from RES). The system can be considered in the market of the primary CHP generators, or as Auxiliary Power Unit (APU) for residential and tertiary application. Thermal integration of an hydride tank with a SOFC system should allow to recover the energy needed for hydrogen desorption on the stack outlet gases flowing at high temperature (800°C).
For the first time a 1kW SOFC stack and an high temperature hydride tank were coupled. The experimental setup and performances of the SOFC stack and magnesium hydride tank are presented. The points considered will be: (a) design and system analysis of the SOFC-MgH_2 integrated system; (b) integration of the system in a test bench; (c) testing and results (d) lessons learned from the experimental session, in order to outline all the unexpected problems (causing failures) of this integrated system, and to provide information for the design of the second release of the system.

A1302

Effects of Multiple Stacks with Varying Performances in SOFC System

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Abstract

Solid oxide fuel cell (SOFC) units with net electric power greater than 20 kWe are usually composed of more than one solid oxide fuel cell stack. If the performance for each single stack is equal, all stacks in optimal layout configuration perform homogeneously. However, typically neither the stacks are exactly equal nor the stack layout in the system is perfect in a sense that the stack placement does not create any disturbance between the stacks. The main parameters determining the SOFC unit efficiency are the electrical power output of the stacks at given current, the power conversion efficiency of the grid connection device, the allowable fuel utilization of the stacks, the required amount of excess air to the stacks, and the electric consumption of required process equipments. Except the power conversion efficiency and internal electric consumption, these parameters are affected by deviations in stack quality and non-idealities in stack arrangement. As the stacks are typically located flow-wise parallel to each other and only the main process flows are actively controlled, the fuel and air flow rates through each single stack, and consequently the fuel and air utilizations in each single stack, in a multiple stack system are determined by the individual flow resistances of the stacks and their corresponding piping arrangement. The flow resistance of a stack is a function of a geometrical factor, dynamic viscosity and temperature profile of the stack. Deviations in the geometrical factor between stacks are caused by manufacturing imperfections and deviations in dynamic viscosity and temperature profile are mainly caused by the performance differences, i.e. differences in stack specific internal resistances and fuel leakage rates. In this contribution, implications of the deviations in the primary parameters, i.e. geometrical factor and stack temperature, are first analyzed. It is shown that both primary parameters have notable effect on the performance of flow-wise parallel connected stack system. Furthermore, system level analyses are conducted in order to study the lifetime expectation of multiple stack systems.

A1303

CFCL SOFC system tested at GDF SUEZ CRIGEN – thermal cycles, Electric Vehicle charging, and ageing

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Abstract

In the framework of the collaboration between the Australian fuel cell manufacturer Ceramic Fuel Cells Limited (CFCL) and the gas and electricity utility company GDF SUEZ, a Solid Oxide Fuel Cell (SOFC) micro-CHP system, named BlueGen, is being tested at the CRIGEN site in Paris. CRIGEN is one of GDF SUEZ' Research and Innovation Division centres.

BlueGen integrates a fuel cell module that can produce power up to 2kWe under a very high efficiency of 60% (from natural gas low heating value to 230V/50Hz AC electricity). This BlueGen is installed within an experimental facility within CRIGEN. It is connected to the electric board and to a 200L Domestic Hot Water tank for the mCHP mode.

These tests are a part of a program, that aims to validate the ability to use fuel cell systems within the residential sector, including a possible field test in a near future. The activities in 2011 and 2012 were divided into two phases. The first phase focused on analysis of resistance to thermal cycles of the BlueGen stack and coupling of a commercial Electric Vehicle with the BlueGen and grid charging. The second phase focuses on the durability study of the BlueGen stack.

The general idea of this experiment is to validate the potential and limitations of a small-scale stationary SOFC system for residential mCHP applications, also coupled with the Electric Vehicle.

The presentation will provide the major results of completed and on-going tests, such as the electrical efficiency, power modulation range, power ramps of the fuel cell (from 0 kW to 1.5kWe), resistance to thermal cycling and ability of the BlueGen to cover the needs of an Electric Vehicle, depending on charging profiles.

A1304

Modeling of the Dynamic Behavior of a Solid Oxide Fuel Cell System with Diesel Reformer

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Abstract

Within the project “ship integration fuel cell – SchIBZ”, a solid oxide fuel cell system is currently being designed and set up. Its purpose is to serve as an auxiliary power unit for larger ship applications, cargo vessels or mega yachts for example. It is therefore supposed to be operated with road diesel oil as a primary fuel, which is converted on-board into a hydrogen- and methane-rich fuel gas in an adiabatic prereforming / steam reforming unit. For sea operation, high system efficiencies over the whole operating range are essential for economic competitiveness against sophisticated diesel combustion engine gensets, which are used nowadays.
The work presented in this paper is about a simulation of the projected fuel cell system including all major system components. Component modeling has been set up based on mass and energy balances, representing each component with lumped parameters. The aim of this work is to study and predict the interactions between different system components. Thereby, special interest is put on the system response to load changes, which is important when designing the electric buffer system. For validation, electric load measurements of the test ship “MS Cellus” are recorded and will be used. The following system conditions serve as benchmarks: steady state at full load (1), steady state at part load (2), load changes (3) and load steps (4). Modeling is carried out in Matlab® Simulink®, using parts of the Thermolib® toolbox.

A1305

System Concept and Process Layout for a Micro-CHP Unit based on Low Temperature SOFC

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Abstract

Anode Supported Cells (ASC) are considered as a promising SOFC technology for achieving higher power densities at significantly reduced operating temperatures. Thereby it is commonly expected to enhance both the profitability and durability of fuel cell systems in real world applications. In the collaborative project LOTUS a micro-CHP system prototype will be developed and tested based on a novel ASC technology with an operating temperature of 650°C. The consortium gathered to work in this project incorporates a number of leading European SOFC-developers, system integrators and research institutes, namely the companies of *HyGear Fuel Cell Systems* (NL), *SOFCPower* (IT) and *Domel* (SLO) as well as the *Fraunhofer IKTS* (D), the *EC Joint Research Centre* (NL) and the *University of Perugia* (IT). The project is funded under EU 7th Framework Programme by the *Fuel Cell and Hydrogen Joint Undertaking* (FCH-JU), grant agreement No. 256694.
In the first project phase the principle system design was developed strictly following a top-down approach based on a system requirements definition, a model based evaluation of applicable system concepts and a final process definition based on layout calculations and parameter studies. The *Fraunhofer IKTS* was leader of the work package system design and modeling. In the second phase of the project all required components and sub-modules are developed with respect to the given process design parameters. The core SOFC stack module with an operating temperature of 650°C will be provided by *SOFCPower* incorporating enhanced ASCs that are newly developed with support of the *University of Perugia*. A compact fuel processing module will be developed by *HyGear* based on air enhanced steam reforming and also enabling for a controllable proportional stack-internal reforming. The advanced fuel processing concept leads to a higher electrical efficiency and a variable power to heat ratio of the system, which is adjustable independently from the electric power output level. A novel exhaust suction fan with a significantly reduced power demand during all operational stages will be provided by *Domel* for system integration. Finally, in the third phase of the project, the setup and commissioning of the system prototype will be carried out, supported by a model based control logic development and failure mode analysis. The testing procedures, data analysis and performance evaluation will be monitored by the *EC Joint Research Centre.*

A1306

Simple and robust biogas-fed SOFC system with 50 % electric efficiency – Modeling and experimental results

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Abstract

The system development process of a simple and robust biogas-fed SOFC system is presented from design to operation.

With a thermodynamic model electric system efficiencies can be calculated taking available fuels and all reforming concepts including anode off gas recycling into consideration. Using the model fuels and system concepts are compared and particularly interesting system concepts such as oxidative dry CO_2 reforming of biogas are identified. Furthermore the model allows the characterization of the reforming conditions necessary to reach the calculated and desired electric efficiencies and its implementation into the system development process.

Naturally the calculations indicate that internal heat management is paramount to reach the intended efficiency. Simulation results are presented comparing characteristics of the reforming step such as necessary heat flux for different fuels and system concepts. Since the strongly endothermic reforming reactions of the developed biogas system require a great heat flow, a new reactor was devised combining reforming and anode tailgas oxidation.

Lastly the system design and operation results are discussed. The design follows a modular scalable concept, in this case employing one stack of the latest IKTS CFY stack-generation producing electric peak power of $P_{el} \cong 0.75$ kW. How a low pressure drop over the entire system of $\Delta p \cong 30$ mbar, a gross electric efficiency of $\eta_{el,gro}=0.42…0.54$ and a gross total efficiency of $\eta_{tot,gro}=0.88…0.94$ are reached depending on electric power output and fuel utilization is illustrated.

A1307

System Integration of Micro-Tubular SOFC for a LPG-Fueled Portable Power Generator

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Abstract

The micro-tubular cell design opens up a promising technology path to the application of Solid Oxide Fuels Cells (SOFC) in very small devices. In contrast to low temperature fuel cells, SOFCs may be operated very easily with available fuels like lighter gas or liquefied petroleum gas (LPG). The utilization of those gaseous fuels requires only a simple pre-reforming step, e.g. based on catalytic partial oxidation (cPOX).

The German start-up company *eZelleron* has developed a low-cost, mass-producible, micro-tubular SOFC design based on injection molded substrates and electrophoretically deposed electrolyte layers. The single cells have a dimension of 3 (dia.) by 45 mm and deliver up to 1.5 W(el) at a fuel utilization of 65 %.

In a collaborative project, *eZelleron* and the *Fraunhofer IKTS* work together on the system integration of those micro-tubular SOFCs for a LPG-fueled portable power generator with a net power output of 25 W(el). The system is expected to provide the technology platform for a first commercial product of the company. The four-year project is publicly funded by the Free State of Saxony and European Regional Development Fund (ERDF).

In this contribution, a brief overview of the development project is given with emphasis on the conceptual approach and the technological solutions for system integration of micro-tubular SOFC.

A1308

System Analysis of Anode Recycling Concepts

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Abstract

The main drivers for anode recirculation are the increased fuel efficiency and the independence of the external water supply for the fuel pre-reforming process. Within the EC-project ASSENT different concepts of anode off-gas recycling loops have been investigated concerning complexity and electrical efficiency.

Different system flow-schemes have been defined and a set of parameters have been elaborated as basis for various calculations. Taking into account the combinations of layouts, cell types, fuel utilization, fuel and recycle ratio the total number of cases modeled was about 220.

All calculated SOFC systems are on a high level of electrical net efficiency in the range of 50 to 66%. The electrical and thermal efficiencies are mainly influenced by the fuel utilization. The electrical efficiency increases and the thermal efficiency decreases with increasing fuel utilization. The total efficiency decreases with increasing electrical efficiency.

The lay-out itself, the choice of fuel gas or the type of cell have minor effects on the system efficiency, which means other criteria are important to choose the "most promising" system lay-out, like number of components, complexity of system, part load operation and so on.

A1309

A model-based approach for multi-objective optimization of solid oxide fuel cell systems

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Abstract

Fuel cell system design is a challenging endeavour due to the many feasible process configurations, the high level of system integration and the resulting component interactions. Multiple economic and environmental design criteria, that often conflict each other, need to be observed simultaneously prior to extensive hardware testing. In such cases process simulations can aid significantly to study system effects while keeping development time short and costs low.

In fuel cell literature optimization of cell design or operational parameters with respect to only objective is much more common than optimization of the process structure itself. Within this work an approach from process system engineering has been extended to allow for multi-objective optimization of fuel cell systems. Thus a comparison of different layouts is quickly possible. The method will be presented for a SOFC based power generator with electrical output of 5 kW_{el}.

The structure of the process layout is analyzed and transferred into a matrix equation of mass and energy balances equations. Free design variables are extracted by elementary matrix manipulations. Based on these variables a steady state process simulation is set up to describe the thermodynamic performance of the fuel cell system including thermal and fluidic interactions. The process model can be easily validated to experimental data. For economic evaluation the simulation roughly computes capital costs of key components.

Pareto optimum for specific costs and net efficiency is numerically computed by a robust genetic algorithm from Matlab. It is shown that a small decline of 2% in efficiency leads to cost saving up to 15 %. With the approach an evaluation of prospective design concepts in terms of efficiency and capital costs is quickly feasible. A sensitivity analysis can assist target-orientated hardware development and focuses on critical system components.

A1310

Portable LPG-fueled microtubular SOFC

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Abstract

The demand for mobile power increases steadily. Mobile devices always seem to be out of power exactly when you need them. Batteries can fulfill the users “thirst” for power only in a short term range. Batteries need a long-term non-mobile recharging time. Thus, for the long-term mobile power supply without recharging interruptions or for mobile recharging of devices gas batteries are the best choice.
eZelleron’s gas battery is a hybrid system of battery and fuel cell. For the user it feels like a standard battery with up to 30 times more energy per weight than a battery. The fuel cell can be easily fueled by everywhere available gases like propane, butane, camping gas or LPG.
The fuel cell is a Solid Oxide Fuel Cell (SOFC), bringing the advantage of fuel flexibility and being free from noble metals. However, SOFCs have known issues, like slow start-up and bad cyclability. In this presentation it is shown, how to overcome these issues by engineering the microstructure.
The mass-manufactured eZelleron microtubular SOFC is operational within seconds. Hence this is a potential technology for mobile/portable power supply of devices.

A1312

SOFC System Model and SOFC-CHP Competitive Analysis

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Abstract

Improving the efficiency of energy conversion devices and reducing green house gas emission are two parallel approaches to improve global environment and sustainability. Compared with other new energy technologies, SOFC-based power system offers superior efficiency and carbon capture potential for building CHP applications in urban areas. SOFC-CHP system operating on natural gas can reach >80% overall efficiency. Studies have shown that it is possible to capture >90% of the carbon input to the system in large scale SOFC systems. For building CHP applications, economical viability and customized system optimization and integration remain as the key challenges of the SOFC technology to the customer.
In this paper, optimization and analysis of an SOFC system are introduced along with the first principal based SOFC components models and system model. With the optimized SOFC system model, map based models of SOFC-CHP systems are generated. Economic competitive analysis of SOFC-CHP is then conducted for selected cities within China. Sensitivity analysis on electricity price, gas price, equipment cost, building type and various CHP options is also included. The results show that under certain conditions, SOFC-CHP systems can provide financial benefits and could be competitive against traditional CHP systems.

A1314

Modeling a start-up procedure of a singular Solid Oxide Fuel Cell

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Abstract

Based on a mathematical model of a Solid Oxide Fuel Cell (single cell, planar design) the laboratory start-up procedure is simulated. Start-up of a fuel cell must be supported by an external source of heat. The simplest solution is to use the burner boot to warm the cell to a temperature which enables it to commence independent work. The amounts of air and fuel supplied to the fuel cell should enable proper operation, in particular the quantities of both fuel utilization and oxidant utilization. In addition, changes in certain parameters interact in a similar way, such as maintaining the desired temperature of fuel cells can be achieved either by reducing/increasing the amount of air and the air temperature. Moreover, both of these parameters are related (the cell cannot be heated up by overly cold air, regardless of the amount). An active start-up system is proposed that comprises regulating the temperature of the air supplied to the cell in relation to the cell temperature.

A1316

3D-Modeling of an Integrated SOFC Stack Unit

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Abstract

Solid oxide fuel cells (SOFCs) are promising candidates for future energy supply by converting the chemical energy of the reactants directly into electrical energy. In this work, a thermo-fluid and electrochemical SOFC stack model of an existing stack is introduced. The stack is made of 30 repeating units in cross-flow design with an internal manifold system.
In SOFC stacks different transport processes are present: heat and mass transfer, fluid flow and electrochemical conversions. Furthermore, different length scales can be found, ranging from several microns for the electrolyte thickness to some decimetres referring to stack height. Therefore, a detailed simulation is computationally expensive. To reduce computational costs, a homogenized description of the electrochemical active area, treated as a porous medium, is introduced. Additionally, the model comprises internal anode and cathode manifolds.
Firstly, a comparison between a detailed and two homogenized thermo-fluid models of one repeating unit will be performed in order to verify our homogenization approach. The homogenized models show good agreement with the detailed case.
In the second part, a homogenized thermo-fluid stack model is integrated into a hotbox environment, leading to a more realistic stack surrounding. In this case, the stack has an open cathode; the air supply through the hotbox induces a more uneven flow distribution at the cathode entrance. The influence of two different heat source distributions inside the stack will be compared.
Finally, a two-dimensional electrochemical model of the active area will be introduced. Temperature distributions for two fuel gas compositions, pure hydrogen and methane, are shown.

A1317

Feasibility Study of SOFC as Heat and Power for Buildings

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Abstract

A major part of energy use and environmental burdens is from the buildings. Fuel cells have the significant potential to mitigate the environmental burdens such as air quality and climate protection. The high efficiency can lead to a significant reduction of fossil fuel use and greenhouse gas emissions. A consideration is given to Solid Oxide Fuel Cell (SOFC) based residential micro-combined heat and power systems. Simplified model is developed in this study to estimate the operation of a residential SOFC. An investigation has been conducted to identify the benefits of the system against the current heating system based on gas and electricity by using the developed model. The systems operation and effects of introducing SOFC system into residential houses are discussed using the daily power and hot water demand of the Japanese residential houses.

A1318

An Innovative Burner for the Conversion of Anode Off-Gases from High Temperature Fuel Cell Systems

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Abstract

The development of fuel cell systems depends without doubt on the development of suitable balance-of-plant components which are able to fulfill new and rather unconventional requirements and specifications. An important issue as such is the utilization of the exhaust stream from the anode of the stack which is indeed a challenging task for the employed combustion systems. The presented work concerns the development of an anode off-gas burner for the needs of the SOFC based micro-CHP unit (1.5 kW_{el} output) which is under development in the framework of the FP7 EU-Collaborative Project “FC-DISTRICT”.
The major technical challenge for the burner development results from the different operating modes of the overall system; very low-calorific value gases have to be converted during steady state operation of the system while CPOX reformate gas with high hydrogen content has to be combusted during start-up and shut-down. In addition, both types of gases have a very high temperature when exiting the anode in the range from 650°C up to 850°C.
With the aim of having simple and compact overall system architecture, the design of the burner is based on a diffusion type flame where the anode off-gases are directly combusted with the exhaust gases from the cathode of the stack. In this way no additional air stream is required for this process and consequently, no additional air blower. The burner has been experimentally characterized for operation with various compositions of anode off-gas depending on the fuel utilization from the SOFC stack. The corresponding thermal power varied from 0.1 kW up to 1.1 kW. Efficient conversion could be achieved in all tested cases with low CO emissions [55 vol.-ppm @ 0% O_2] complying with the regulations of DIN EN 50465. Tests were also performed with CPOX reformate varying the corresponding thermal power in the range from 0.9 kW up to 3.8 kW. The obtained results are presented and analyzed in the current paper.

A1319

Technical progress of partial anode offgas recycling in propane driven Solid Oxide Fuel Cell system

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Abstract

SOFC-systems with either internal or external reforming allow the use of common hydrocarbon fuels like natural gas, LPG or diesel. Especially propane is easy to handle and widely used in camping and leisure applications. Because commercially available SOFC stacks are not yet suited for exclusive internal reforming, different approaches for the external reforming are considered today, e.g. steam reforming (SR) with water or partial oxidation (POX) with air-oxygen. However, these concepts suffer either from complex auxiliary units for the water conditioning or low electrical system efficiency.
A highly effective alternative is the reforming of hydrocarbon fuels with the anode off gas (AOG) of the SOFC, promising electrical system efficiencies above 60 %. Partial recycling of the AOG supplies the reformer with the SOFC oxidation products steam and CO_2 as oxygen carriers. The conversion of the hydrocarbon to hydrogen and carbon monoxide for the SOFC via combined steam-(SR) and dry-reforming (DR) yields a higher chemical energy input to the stack compared to the fuel energy fed to the reformer. The required heat for the endothermic steam- and dry-reforming of propane fuel can be provided by combustion of the remaining AOG in the burner and transferred to the reforming reactor.
A compact propane driven SOFC-system with recycling of hot AOG is developed at CUTEC Institute with partners from the fuel cell research center ZBT GmbH (ZBT Duisburg, Germany), Institute for heat- and fuel technology (IWBT, TU Braunschweig) and Institute of Electrical Power Engineering (IEE, TU Clausthal). The system extends the commercially available integrated stack module (ISM) of Staxera GmbH (Dresden, Germany) by the required fuel processing and auxiliary units and is expected to yield an electrical power output of 950 W_{el} (gross) by using a propane flow of 1.0 l_N/min. Thus, electrical system efficiency will be 61 % (based on propane LHV).
CUTEC developed a custom-made hot gas ejector that uses the already pressurised propane from standard gas bottles as propellant gas. It leaves the ejector nozzle at high velocity and hereby entrains the AOG. A Laval nozzle is used to accelerate the propane stream to supersonic speed and enable a recycle ratio sufficient for soot-free reformer operation. As the ejector has no moving parts it is expected to work robust, even at the high operating temperatures of about 600 °C.
The system concept and design options for thermal integration and compactness as well as results for the component development and tests will be discussed. Ejector performance data will be presented based on experimental results.

A1320

Lower Saxony SOFC Research Cluster: Development of a portable propane driven 300 W SOFC-system

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Abstract

Portable power generation is expected to be an early and attractive market for the commercialization of SOFC-systems. The competition in the segment of portable power generation is strong at costs per kilowatt, but weak in terms of electrical efficiency and fuel flexibility. Propane is attractive because of its decentralized availability with easy adaptability to other fuels, such as camping gas, LPG or natural gas.
The Lower Saxony SOFC Research Cluster was initiated to bundle the local industrial and research activities on SOFC technology for building a stand-alone power supply demonstrator with the following features:

- Net system electrical power of 300 W,
- High net efficiency of >35 %,
- Compact mass and volume (less than 40 liters and 40 kg),
- Time to full load in less than 4 hours.

Multiple innovations shall be realized within the network project to improve system characteristic:

- Stacked, planar design of all main components to reduce thermal losses and permit a compact set-up,
- Endothermic propane reforming with anode offgas to increase electrical efficiency without complex water treatment,
- Operation management with reduced sensor hardware to decrease internal energy consumption,
- System and component design suited for a subsequent transfer towards an industrial prototype development.

The SOFC system is based on the Mk200 stack technology of Staxera GmbH, Dresden, including ESC4 cells of H.C. Starck. Anode offgas recycle in conjunction with a combined afterburner/reforming-unit in counter flow configuration is used to generate SOFC fuel gas. Different technical approaches are considered and evaluated for the anode offgas recirculation unit. A heat exchanger tailored to the specific boundary conditions and an advanced compression system with active control of stack compression are developed. The system casing is purged with the cathode air to minimize thermal losses.

A1321

Portable 100W Power Generator based on Efficient Planar SOFC Technology

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Abstract

An ultra-compact, portable solid oxide fuel cell (SOFC) system is presented that is based on multilayer and ceramic technology and that uses commercially available fuels. The eneramic® SOFC system is intended for use in leisure, industrial and security applications. In these markets, portability, simplicity and ease of use have a higher priority than efficiency, much in contrast to stationary applications. Thus the eneramic® system was designed to run on widely available propane/butane fuels and applies a dry reforming process (CPOx). Bio-ethanol fuels have been tested successfully as well after small modifications at system level.
In order to achieve a compact system with good thermal integration, low cost and ease of assembly the gas processing unit consists of a metallic multilayer assembly. Thus the hotbox core comprises the planar stack on top, the central media distribution module, and the heat management module below in a single, mechanically compact module. The applied multilayer technology offers new design opportunities for compact internal gas manifolding with low pressure loss. The stack itself is based on IKTS electrolyte supported cells (ESC). 3YSZ based ESCs were chosen for their low cost and for their good mechanical and redox stability. The long-term stability of SOFC stacks was tested over more than 3,000 hours with power degradation below 1.0 %/1,000 h. The results show that the compact planar SOFC stack is capable to survive the expected system life time.
Due to its good thermal packaging, the current system achieves gross efficiencies up to 36% and a net efficiency of 30% with off-the-shelf BoP components, which is at the forefront among those devices. With the developed hotbox core life time targets up to 2000 hrs have been reached in stationary operation mode. Here the test results of the new eneramic hotbox generation will be emphasized, that exceeds previous generation in terms of efficiency and lifetime. At system level the new stand alone prototype of the eneramic system will be introduced below.

A1322

SchIBZ – Application of SOFC for onboard power generation on oceangoing vessels

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Abstract

The German funded development project SchIBZ is an effort of 8 European partners to develop and demonstrate a diesel fueled 500kW power unit based on SOFC.

Global shipping is confronted with decreasing emission limits and increasing pressure for higher efficiency (or economy). New technologies are sought to combine lower emissions (gases and noise) with lower maintenance. Although a lot can be done with supplements to diesel engines fuel cells are at time being the only technology with the potential for a big step in improvement.

The system will be able to operate on low sulphur diesel oil with 15ppm sulphur as it is used for road traffic in many areas of the world. With an intended unit size of 500kW the system is sufficient to supply in a group of 3 to 4 units a vessel completely with electrical power. Regardless of this power requirement the system is due to its modularity adaptable to other requirements. To enhance the dynamic behavior the system is accompanied by a buffer storage. The outstanding feature of the process is the simplicity which additionally allows for a convenient exhaust air usage.

The consortium consists of Blohm + Voss Naval, Howaldtswerke-Deutsche Werft, Topsoe Fuel Cell, Oel-Waerme-Institut, Imtech Marine Germany, Germanischer Lloyd, Helmut-Schmidt-University and the Rörd Braren shipping company. These partners combine large experience in fuel cell and process technology and ship building.

The paper will describe the configuration and principle function of the system and the benefits and technical aspects of the integration in oceangoing vessels. Furthermore it will describe how the demonstration onboard a general cargo vessel will be done.

A1323

Bio-Fuel Production Assisted with High Temperature Steam Electrolysis

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Abstract

Two hybrid energy processes that enable production of synthetic liquid fuels that are compatible with the existing conventional liquid transportation fuels infrastructure are presented. Using biomass as a renewable carbon source, and supplemental hydrogen from high-temperature steam electrolysis (HTSE), these two hybrid energy processes have the potential to provide a significant alternative petroleum source that could reduce dependence on imported oil.

The first process discusses a hydropyrolysis unit with hydrogen addition from HTSE. Non-food biomass is pyrolyzed and converted to pyrolysis oil. The pyrolysis oil is upgraded with hydrogen addition from HTSE. This addition of hydrogen deoxygenates the pyrolysis oil and increases the pH to a tolerable level for transportation. The final product is synthetic crude that could then be transported to a refinery and input into the already used transportation fuel infrastructure.

The second process discusses a process named Bio-Syntrolysis. The Bio-Syntrolysis process combines hydrogen from HTSE with CO from an oxygen-blown biomass gasifier that yields syngas to be used as a feedstock for synthesis of liquid synthetic crude. Conversion of syngas to liquid synthetic crude, using a biomass-based carbon source, expands the application of renewable energy beyond the grid to include transportation fuels. It can also contribute to grid stability associated with non-dispatchable power generation. The use of supplemental hydrogen from HTSE enables greater than 90% utilization of the biomass carbon content which is about 2.5 times higher than carbon utilization associated with traditional cellulosic ethanol production. If the electrical power source needed for HTSE is based on nuclear or renewable energy, the process is carbon neutral. INL has demonstrated improved biomass processing prior to gasification. Recyclable biomass in the form of crop residue or energy crops would serve as the feedstock for this process. A process model of syngas production using high temperature electrolysis and biomass gasification is presented. Process heat from the biomass gasifier is used to heat steam for the hydrogen production via the high temperature steam electrolysis process. Oxygen produced form the electrolysis process is used to control the oxidation rate in the oxygen-blown biomass gasifier.

A1324

Operating Strategy of a Solid Oxide Fuel Cell system for a household energy demand profile

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Abstract

A combined heat and power system of a solid oxide fuel cell was evaluated using a commercial tool Matlab/simulink. A zero dimensional approach of a solid oxide fuel cell model was considered for simulations. Among the different kinds of fuel cells, the operating temperature of a solid oxide fuel cell is significantly high; this makes SOFC a suitable system to operate for household applications. Furthermore, the potential of a conventional CHP system lies in the ability to adapt to the dynamic behavior of electricity and heat consumption. Also, the CHP system has to satisfy the weak correlation between the existing electricity and heat demand profiles. Unlike most of the other conventional CHP system the ratio of electrical energy to heat energy of a SOFC can be varied continuously. This makes SOFC a potential system to fulfill the demand profile of a multi-family house.

A1325

Leading the Development of a Green Hydrogen Infrastructure – The PowertoGas Concept

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Abstract

Germany's share of renewable energies in the electricity mix is over 20 percent and rapidly increasing. The federal government expects renewable energies to account for 35 percent of Germany's electricity mix by 2020, 50 percent by 2030 and 80 percent by 2050. According to the German Energy Agency, multi-billion euro investments in energy storage are expected by 2020 in order to reach these goals. The growth of this fluctuating energy supply has created demand for innovative storage technology in Germany and is accelerating its development. Along with battery and smart grid technologies, hydrogen is expected to be one of the lead technologies. The German Hy study – commissioned by the German Federal Ministry of Transport, Building, and Urban Affairs – provides a road map for the development of a hydrogen infrastructure. At the same time, the German federal states – namely Brandenburg, Hamburg and Schleswig-Holstein - are also examining the feasibility of generating and commercializing hydrogen from wind energy through electrolysis. The New Berlin Brandenburg International Airport, which is slated to open in 2012, serves as a benchmark project for hydrogen developments. It will feature an integrated energy storage concept that includes a fueling station for green hydrogen serving both stationary and mobile applications, which will be built by Total and Enertrag. Deutsche Bahn AG is also active in this field. Hydrogen in combination with renewable energy generation provides the focal point in the next generation of rail mobility. The Germany Technical and Scientific Association for Gas and Water sees opportunities for hydrogen to be fed into the existing natural gas grid. According to the current DVGW-Standards natural gas in Germany can contain a volume of 5 to 9,9 percent hydrogen. This could serve both for fuel and for the storage of extra energy produced by renewable sources. This hydrogen could then be drawn upon to provide electricity by means of CCGT (combined cycle gas turbines) or CHP (combined heat and power) using for example fuel cells. The name of this concept is PowertoGas. Several demonstration projects will be rolled out till 2013 in order to develop business models (for storage, production and trade of „green Gas") and devices (Electrolyzers, fuel cells, smart gas metering, compressors, pipes and storage devices) that will enable the implementation of this concept on a broad scale. Germany is pioneer in this field. Further countries in Europe like France, the Scandinavian countries and UK are also developing H2 based smart solutions and can benefit from the experience of German project participants, value chain and RnD institutes.

A1327

Dynamic Modeling of Solid Oxide Fuel Cell Systems for Commercial Building Applications

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Abstract

A dynamic SOFC system model has been developed for the purposes of performing an engineering feasibility analysis on recommended integrated system operating strategies for building applications. Included in the system model are a dynamic SOFC stack, dynamic steam pre-reformer and other balance-of-plant components, such as heat exchangers, compressors and a tail gas combustor. Model results show suitably fast electric power dynamics (12.8 min for 0.5 to 0.6 [A/cm^2] step; 16.7 min for 0.5 to 0.4 [A/cm^2] step) due to the fast mass transport and electrochemical dynamics within the SOFC stack. The thermal dynamics are slower (17.4 min for 0.5 to 0.6 [A/cm^2] step; 25.0 min for 0.5 to 0.4 [A/cm^2] step) due to the thermal coupling and thermal capacitance of the system. However, these transient results are shown to be greatly dependent upon SOFC system operating conditions as evidenced by settling times of greater than 2 hours for a 0.3 to 0.24 [A/cm^2] step. In addition, system design implications on system dynamic response are revealed with particular attention on the effect of an external pre-reformer and the configuration of the process gas heat exchanger. Preliminary results are summarized within the context building load profiles and demand requirements.

A1328

Evaluating the Viability of SOFC-based Combined Heat and Power Systems for Biogas Utilization at Wastewater Treatment Facilities

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Abstract

Biogas has been identified as an attractive fuel for solid oxide fuel cells (SOFCs) due to its high methane content and its renewable status. Current experimental and modeling research efforts in this field have focused mainly on single-cell and small-scale SOFC system performance evaluation. In this paper a large scale biogas source (~15.5 MW) from a wastewater treatment facility is considered for integration with an SOFC-based combined heat and power (CHP) system. Data concerning biogas fuel flow rate and composition have been acquired from a wastewater reclamation facility in Denver, Colorado and are used as inputs to a steady-state SOFC-CHP system model developed with Aspen Plus. The proposed system concept for this application comprises an advanced SOFC system with anode gas recirculation equipped with biogas clean-up and a waste heat recovery system. The system performance is evaluated at near atmospheric pressure with a 725°C nominal stack operating temperature and system fuel utilization of 80%. The average biogas fuel input has a composition of about 60% CH_4, 39% CO_2, and 1% N_2 on a dry molar basis. The SOFC-CHP system employs 80% internal reforming at a steam-to-carbon ratio of 1.2. The system offers a net electrical efficiency of 51.6% LHV and a net CHP efficiency of 87.5% LHV. The economic viability of the SOFC-CHP system is explored through bottom-up capital costing of the hardware and examination of the life cycle costs of the plant. The influence of the operating parameters on the system life cycle costs are investigated and discussed. System techno-economic model results are presented and compared to biogas-supplied combustion turbines currently installed at the facility which operate with an average net electrical efficiency of about 25%-LHV.

A1401

SOFC for Distributed Power Generation

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Abstract

SOFC constitutes a preferred means for **Distributed Energy Production**, thanks to its ability to produce electrical and heat power, with high efficiency and fuel flexibility.

Europe's energy challenges require a transition from hydrocarbon economy to hydrogen-energy economy. This will in particular allow reduction of carbon emissions, ensure energy security, and address the renewables intermittency conundrum. In addition to technical and political challenges, the investment challenge has also to be considered to make these alternatives affordable.

The advantages of distributed generation in the current European energy landscape are several, such as localised DG, close and responsive to demand, smaller affordable units, the potential for easier mass adoption and for local H2 use. In this context, the **Solid Oxide proposition** fulfills most of these, providing a local, affordable, efficient, and multi-fuel solution.

Solid Oxide challenges are reviewed based on results presented during the xxth SOFC forum and on a revue of systems that are being trialed. Some understanding on what we have compared to what we target as 'Holy Grail' is given, including the need for durable systems, not just cells and stacks.

The presentation is concluded with some considerations on **commerce vs science** and on **Economics** considerations: It's all about cents/kWhr as 'we like green but we wont pay'….

B0401

Fundamental Material Properties Underlying Solid Oxide Electrochemistry

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Abstract

The concept of solid oxide electrochemistry, which we understand as the electrochemistry of cells based on oxide ion conducting electrolytes of non-stoichiometric metal oxides, is briefly described. The electrodes usually also contain ceramics. The chemical reactants are in gas phase, and the electrochemical reactions take place at elevated temperatures from 300 and up to 1000 °C. This has as consequence that the region around the three-phase-boundary (TPB), where the electron conducting electrode, the electrolyte and the gas phase reactants meet, is the region where the electrochemical processes take place. The length of the TPB is a key factor even though the width and depth of the zone, in which the rate limiting reactions take place, may vary depending of the degree of the electrode materials ability to conduct both electrons and ions, i.e. the TPB zone volume depends on how good a mixed ionic and electronic conductor (MIEC) the electrode is.

Selected examples of literature studies of specific electrodes in solid oxide cells (SOC) are discussed. The reported effects of impurities - both impurities in the electrode materials and in the gases – point to high reactivity and mobility of materials in the TPB region. Also, segregations to the surfaces and interfaces of the electrode materials, which may affect the electrode reaction mechanism, are very dependent on the exact history of fabrication and operation. The positive effects of even small concentrations of nanoparticles in the electrodes may be interpreted as due to changes in the local chemistry of the three phase boundary (TPB) at which the electrochemical reaction take place. Thus it is perceivable that very different kinetics are observed for electrodes that are nominally equal, but fabricated and tested in different places with slightly different procedures using raw materials of slightly different compositions and different content of impurities. Further, attempts of quantitative general description of impedance and i-V relations, such as the simple Butler-Volmer equation, are discussed. We point out that such a simple description is not applicable for composite porous electrodes, and we claim that even in the case of simple model electrodes no clear evidences of charge transfer limitations following Butler-Volmer have been reported.
Thus, we find overall that the large differences in the literature reports indicate that no universal truth such as “this is the rate limiting step of H_2 oxidation in a Ni-zirconia cermet electrode...” will ever be found because the actual electrode properties are so dependent on the fabrication and operation history of the electrode. This does not mean, however, that deep knowledge of mechanisms of specific SOC electrodes is not useful. On the contrary, this may be very helpful in the development of SOCs.

B0402

La and Ca doped $SrTiO_3$: A new A-site deficient strontium titanate in SOFC anodes

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Abstract

Doped strontium titanates have been widely studied as potential anode materials in solid oxide fuel cells (SOFCs). The high n-type conductivity that can be achieved in these materials makes them well suited for use as the electronically conductive component in SOFC anodes. This makes them a potential alternative to nickel, the presence of which is a major cause of degradation due to coking, sulphur poisoning and low tolerance to redox cycling. As the electrocatalytic activity of strontium titanates tends to be low, impregnation with oxidation catalysts, such as ceria and nickel is often required to obtain anode performances that can compete with Ni-YSZ cermets. Here the stability issues due to nickel should be reduced due to the small loadings and its non-structural function.

Here anode performance results are presented for an A-site deficient strontium titanate co-doped with lanthanum and calcium on the perovskite A-site, $La_{0.20}Sr_{0.25}Ca_{0.45}TiO_3$ ($LSCT_{A-}$). $LSCT_{A-}$ anodes and LSM cathodes were screen printed on 160 µm thick 6-ScSZ electrolyte supports. The $LSCT_{A-}$ anode backbone showed poor electrode performance, but its conductivity was sufficient to keep ohmic losses low. Upon impregnation with combinations of ceria and nickel, ohmic losses and polarisation impedances are significantly reduced, resulting in a drastic improvement in anode performance. Unexpectedly, the performance of cells with both ceria and nickel impregnation showed an improvement upon redox cycling. A stable area specific resistance of 0.37 Ωcm^2 was achieved after 20 redox cycles and 250 hours of operation at 900°C in H_2 with 8% H_2O, showing excellent redox stability.

B0403

Thermomechanical Properties of the Reoxidation Stable Y-$SrTiO_3$ Ceramic Anode Substrate Material

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Abstract

The mechanical robustness is an important aspect to warrant a long-term reliable operation of a solid oxide fuel cell (SOFC) stack. During assembling and operation the ceramic cell is exposed to mechanical loads. In the planar anode-supported SOFC design the brittle substrate is of main importance with respect to the failure potential under mechanical loads. The current work concentrates on the mechanical properties of Y-$SrTiO_3$ ceramic anode substrate material. Contrary to conventional Ni/8YSZ cermet materials the Y-$SrTiO_3$ is expected to be reoxidation stable, a key aspect for long-term operation under realistic operation conditions where intermediate stops of the fuel cell operation may lead to a change from a reducing atmosphere (during the operation) to an oxygen-containing atmosphere (air). Relevant mechanical properties have to be characterized to conclude if this new material fulfills the requirements to warrant stable operation of SOFC stacks. Room temperature microindentation permitted a determination of Young's modulus and hardness, whereas the temperature dependence of the Young's modulus was measured with a resonance based method up to ~ 950 °C. Since high porosity is vital for anode materials, the effective Young's modulus porosity dependency was measured with the microindentation method at room temperature and compared to available strength data. The fracture toughness was assessed using a combination of pre-indentation induced cracks and ring-on-ring bending test, the so-called indentation strength method. Creep rates for Y-$SrTiO_3$ were measured at high temperatures (800 °C and 900 °C) for different loads in a 3-point bending configuration. Post-test fractographic analysis was performed using stereo-, confocal and scanning electron microscopy, which revealed important information on fracture origins and critical defects in the material.

B0404

Doped $La_{2-X}A_XNi_{1-Y}B_YO_{4+\delta}$ (A=Pr, Nd, B=Co, Zr, Y) as IT-SOFC cathode

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Abstract

The search for new Solid Oxide Fuel Cells (SOFC) cathodes with mixed ionic and electronic conductivity (MIEC) has achieved high interest during the last years. These MIEC cathodes allow the enlargement of the three phase boundary (TPB) area to cover the whole electrode surface, thus increasing the number of reaction sites and the electrochemical performance. The oxygen reduction reaction is improved. As a consequence, the SOFC operation temperature can be reduced up to the intermediate temperature range (IT-SOFC) and then the cost of the whole system.
The present work is focused on the study of different cathodes for IT-SOFC based on the $La_{n+1}Ni_nO_{3n+1}$ (n=1, 2 and 3) Ruddlesden-Popper series. $La_2NiO_{4+\delta}$ consists of alternating perovskite and rock-salt layers and shows high electronic and ionic conductivity, appropriate thermal matching with common electrolytes and good stability in CO_2-bearing atmospheres in contrast to well-known Ba or Sr bearing MIEC perovskites, e.g., $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ [1]. The oxygen ion transport is produced via interstitial incorporation of oxygen ions in the lattice [2]. In the present work, in order to increase the total conductivity and the electrocatalytic properties of this series of MIEC materials, different structural substitutions have been done in the $La_{2-X}A_XNi_{1-Y}B_YO_{4+\delta}$ system (A=Pr, Nd, B=Co, Zr, Y).

Electrochemical properties of the different $La_{2-X}A_XNi_{1-Y}B_YO_{4+\delta}$ materials have been studied by means of electrochemical impedance spectroscopy (EIS) of symmetrical cells. Gadolinia-doped ceria (GDC) has been used as electrolyte [3]. The microstructure of the cathode materials has been improved while the electrochemical behavior has been studied as a function of the temperature and the oxygen partial pressures. Moreover, the effect of CO_2 in the performance has been addressed for selected cathode compositions.

Among the different materials tested the double substitution in A and B ($La_{1.5}Pr_{0.5}Ni_{0.8}Co_{0.2}O_{4-\rho}$) presents the lowest polarization resistance in the range of temperatures measured (900-450 ºC). Furthermore, the stability of the electrochemical as IT-SOFC cathode was confirmed over 100 h.

B0405

Development and Characterization of LSCF/CGO composite cathodes for SOFCs

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Abstract

The development of a high-performance oxygen electrode for SOFCs in order to achieve high power density at a stack level is still challenging. It is important to emphasize the factors controlling the efficiency of the cathode. Over the intrinsic electro-catalytic activity of the cathode material itself toward the oxygen reduction, the microstructural parameters such as the porosity, the tortuosity or the particle size are of major importance in the definition of the electrochemical active surface area. Moreover, current collection is also a critical issue to be insured in order to avoid any current constriction yielding to the reduction of the active surface area. The development of highly efficient cathode consists thus in addressing each of these issues. About the contacting, the use of conducting paste for the study of cathode with small active surface area (<1 cm^2) could lead to discrepancies in the performance when such layers are implemented into stackable cells.
In this paper we focus on the development and characterization of composite cathodes produced by suspension spraying and sintering without addressing the contacting issue in order to develop the most robust cathode which can be implemented at a stack level, i.e. an efficient cathode without improved contacting. Different symmetrical cells were produced by varying the LSCF/CGO ratio with an active surface area of about 12.57 cm^2. Cells were contacted with a fine platinum mesh without any contacting paste and electrochemical impedance spectra (EIS) were recorded in static ambient air in the frequency range 10 mHz – 100 kHz between 500°C and 800°C. The serial resistance (*R*s) and the total polarization resistance (*R*p) were both quantified. Equivalent circuit modeling was used to identify phenomena involved in the cathode process and data were coupled with morphological characteristics measured after testing (porosity, pore size and total pore surface area). With our test configuration, the lowest obtained total area specific resistance (ASR) was 0.094 $\Omega.cm^2$, from which 70% were due to gas concentration polarization.
The obtained experimental results were used to develop an elementary kinetic model of the oxygen reduction at the cathode, including elementary heterogeneous chemistry, electrochemical charge-transfer, ionic/electronic conduction, multicomponent porous-phase and channel-phase transport. This model will aim in the future at the microstructural optimization of the cathode. In this contribution, results about the performance of the composite cathodes correlated with microstructural data will be presented and discussed; the kinetic model based on these will be shortly introduced, and will be the object of a dedicated communication.

B0406

Effect of Ultra-thin YSZ Blocking Layer on Performance of 1 μm-thick GDC Electrolyte SOFC

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Abstract

In the current study, the thickness of the gadolinia-doped ceria (GDC) electrolyte was fixed as 1 μm and the thickness of the yttria-stabilized zirconia (YSZ) blocking layer was reduced from 200 nm to below and the effects were observed. The maximum thickness of YSZ was determined as 200 nm because the resistance of 200 nm-thick YSZ is similar to that of 1 μm-thick GDC at 600 °C. By this approach, we could achieve both a high OCV and a power output of the GDC electrolyte cell. By inserting the blocking layer, the OCV substantially increases from ~0.6 V to over 1 V. As a result, the maximum power density of the GDC TF-SOFC increases by approximately three times to that of the cell without a blocking layer. The effects of the insertion of the ultra-thin YSZ blocking layer and comparison between GDC TF=SOFC and YSZ electrolyte TF-SOFC will be presented.

B0407

Microstructural and electrochemical characterization of thin La0.6Sr0.4CoO3-δ cathodes deposited by spray pyrolysis

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Abstract

Mixed ionic-electronic conducting $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ (LSC) has recently drawn much attention as one of the most active materials for intermediate temperature SOFC cathodes. The electrochemical kinetics is believed to be limited by oxygen incorporation at the perovskite/air interface. Hence improvement of the cathode performance can be achieved by increasing the number of sites for oxygen exchange. This is realized either by making the electrode thicker and/or by producing nanosized LSC grains.
Spray pyrolysis (SP) constitutes a cost-effective alternative technique to vacuum-based deposition techniques, such as pulsed laser deposition (PLD) and sputtering, to produce such nanocrystalline components for thin films SOFC and micro-SOFC. Its versatility in terms of processing parameters (e.g. deposition temperature, precursor concentration, flow rate …) enables to fabricate a large variety of electrodes with various microstructures, grain sizes and pore sizes.
In this work, nanoporous $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ cathodes are sprayed on yttria-stabilized zirconia (YSZ) and gadolinium-doped ceria (GDC) electrolyte substrates. As-deposited layers are amorphous. The desired perovskite phase, electrical conductivity and porosity develop upon annealing at ca. 500-600°C. Grain and pore size from 10 to 50 nm can be obtained by adjusting the heat-treatment of the as-deposited layers. Power density data of anode-supported SOFC shows that SP-LSC and PLD-LSC cathodes yield similar electrochemical performance in the 450-650 °C range. This contribution will also present quantitative microstructure analyses of annealed electrodes (such as specific surface area, constrictivity and tortuosity, using continuous phase size distribution), area-specific resistance values of LSC/GDC (or YSZ)/ LSC symmetrical cells as well as results on the SP-LSC/YSZ chemical compatibility and the need of a GDC interlayer.

B0408

$LaNi_{0.6}Fe_{0.4}O_3$ cathode performance on $Ce_{0.9}Gd_{0.1}O_2$ electrolyte

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Abstract

The over potential of a cathode in solid oxide fuel cells (SOFCs) is still required to be reduced for practical applications. $LaNi_{0.6}Fe_{0.4}O_3$ (LNF) is one of the candidate cathode materials for SOFCs since it has a high electrical conductivity at the operation temperature and the high stability against chromium poisoning. The present authors tried to give an idea of LNF cathode reaction mechanism in the view of the electrochemical properties and the interaction of oxygen and oxide ionic diffusion. A half button-cell test was carried out with LNF cathode on $Ce_{0.9}Gd_{0.1}O_2$ (GDC) electrolyte in a partial pressure of oxygen ($p(O_2)$) ranging from 10-2 to 1 bar at an operation temperature ranging from 873 to 1073K. The cathode performance was tested by electrical impedance spectroscopy (EIS) which results show that the area specific resistance (Rp) is about 0.98 Ωcm2 at T = 1023K and p(O2) = 10-0.68 bar and its activation energy is 1.8 eV. The p(O2) dependence of Rp is 0.34. By analyzing the EIS results, it is clear that the charge transfer and/or surface reaction of oxygen on the LNF cathode are equally dominant for the overall resistance.

B0409

Compatibility and Electrochemical Behavior of $La_2NiO_{4+\delta}$ on $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$

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Abstract

$La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$ (LSGM) is an oxygen conducting electrolyte material widely used in solid oxide fuel cells (SOFCs), and has higher ionic conductivity compared to the conventional electrolyte material YSZ. However LSGM has received relatively little research in electrolysis mode. $La_2NiO_{4+\delta}$ (LNO) is a mixed ionic-electronic conducting layered perovskite with K_2NiF_4 type structure which conducts ions via oxygen interstitials and so accommodates oxygen excess. LNO has shown promising results as an SOFC/SOEC electrode [1]. In this work we studied the performance of LNO electrodes on the LSGM electrolyte material.

The cell was characterised by symmetrical and three electrode electrochemical measurements using AC impedance spectroscopy. Conductivity and ASR values were obtained in the temperature range 300 – 800°C and by subjecting the electrolysis cathode to varied DC bias potentials. Material reactivity was determined using XRD and *in-situ* high temperature XRD. Below 900°C no secondary phases were observed to form between the LNO and LSGM powders. Powders heated to 1100°C show evidence of the formation of higher order Ruddlesden-Popper (RP) phases such as $La_3Ni_2O_7$.

LNO on LSGM shows promising electrochemical performance but is shown to react at high temperatures, forming RP phases. Due to these results further work will investigate other lanthanum perovskite based electrodes, such as $La_{1.7}Sr_{0.3}Co_{0.3}Ni_{0.7}O_4$ with the LSGM electrolyte.

B0410

Single Step Process for Cathode Supported half-cell

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Abstract

Tape casting is a widely used shaping technique to produce large area, flat ceramic electrodes with a microstructure suitable for solid oxide fuel cell (SOFC) applications. This cheap and easily scalable ceramic process generally makes use of pore formers to produce elements with the desidered porosity. Thin film electrolyte is generally fabricated on the green electrode substrate by screen-printing; the entire system is finally co-sintered to obtain the electrolyte/electrode bilayer.
In this study the possibility to produce a SOFC half-cell constituted of porous $La_{0.8}Sr_{0.2}MnO_3$-$Ce_{0.8}Gd_{0.2}O_2$ (LSM-GDC) supporting cathode and GDC dense electrolyte in a single thermal step was investigated. To avoid the use of pore formers, the reactive sintering approach was considered. The precursor decomposition during a single thermal treatment of calcining-debonding-sintering was exploit to generate at the same time, the suitable porosity and the $La_{0.8}Sr_{0.2}MnO_3$ phase. Different sintering aids were tested for densifying the GDC layer. Carefully studying the effect of the reactive sintering on the sintering profile and the structure integrity of the cathode-supported half-cell allows to successfully obtain bilayers of 5x5cm^2. To the author knowledge this is the first time that a dense electrolyte membrane has been obtained in a single step onto a supporting cathode produced by tape casting adopting the reactive sintering approach.

B0411

Modified oxygen surface-exchange properties by nanoparticulate Co_3O_4 and SrO in $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-film cathodes

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Abstract

Low-temperature operation (400 to 600 °C) of solid oxide fuel cells has generated new concepts for materials choice, interfacial design and electrode microstructures.
In previous studies it was shown, that nanoscaled and nanoporous (particle and pore size in the range of 15…150 nm) $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-film cathodes (film thickness 200…400 nm) derived by metal organic deposition (MOD) exhibited extremely low area specific polarization resistances, as low as 7.1 $m\Omega \cdot cm^2$ at 600 °C, 75 $m\Omega \cdot cm^2$ at 500 °C and 1.94 $\Omega \cdot cm^2$ at 400 °C. Extensive analysis of the impedance and microstructural data revealed, that this performance increase cannot be explained by the nanoscaled microstructure alone and that nanoscaled MOD-derived $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ exhibits an increased oxygen surface-exchange coefficient of up to factor 47 in comparison to the values reported in literature for bulk material. Furthermore, nanoparticulate Co_3O_4 was detected on the surface of the $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-films by conclusive transmission electron microscopy investigations.
Goal of this study now is, to investigate the effect of nanoparticulate Co_3O_4 and also SrO on the electrochemical performance of $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-film cathodes and to elucidate the mechanism behind this considerable oxygen surface-exchange improvement.

We will show the results of chemically modified nanoscaled $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-film cathodes, where the local chemical composition was deliberately altered by either depositing SrO on the surface of stoichiometrically prepared nanoscaled $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-films or by directly deriving chemically modified $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin-film cathodes with a slight excess of A- or B-site cations.

B0412

La10-xSrxSi6O26 coatings elaborated by DC magnetron sputtering for electrolyte application in SOFC technology

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Abstract

It is now well known that one of the locks in the use of SOFC at industrial scale is their high operating temperature. The possible solutions to overcome this drawback are the reduction of the electrolyte thickness and the use of anion conductive electrolytes better than YSZ. A serious candidate to replace YSZ as electrolyte is lanthanum silicate elaborated as thin film. Numerous methods are available and among them, the magnetron sputtering technique is clean and environmentally friendly. In previous studies, we have shown the possibility of using this technique for deposition of conventional electrolyte materials for SOFC [1] and new electrolyte materials [2].

In this study, La-Sr-Si metallic coatings were synthesized by magnetron sputtering of lanthanum, strontium and silicon targets in pure argon atmosphere. After the deposition stage, the ceramic apatite-structure coatings were obtained by thermal oxidation in air. The structural and chemical features of these films have been assessed by X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). The electrical properties were determined by complex impedance spectroscopy in planar configuration. The films with a (La+Sr)/Si atomic ratio close to the apatite composition $La_9Sr_1(SiO_4)_6O_2$ deposited on different substrates were initially amorphous. After thermal oxidation at 1173 K in air, the coating crystallised under the expected apatite structure. SEM observation revealed that the film compactness and thickness increased after thermal oxidation. The electrical measurements carried out under air as a function of temperature (1200 to 800 K) show only one contribution for the apatite layer on the Nyquist diagram. The electrical properties were controlled by the Arrhenius law and present a very high resistance. The first electrochemical single cell measurements performed on a Ni-apatite/apatite/$Pr_2NiO_{4+\square}$ assembly showed OCV is around 440 mV. This value is low in comparison with the literature and the 1V obtained in the same configuration with the undoped apatite electrolyte.

B0413

A review on thin layers processed by Atomic Layer Deposition for SOFC applications

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Abstract

The use of this layers for intermediate and low-temperature solid oxide fuel cells application has become one of the most significant topics for several issues, as thin-layered electrolytes, protective layers, e.g. for metallic interconnects, diffusion barriers and catalysts. In this sense, ultrathin layers of high quality have attracted particular attention. Among the most performing techniques, one can mention atomic layer deposition (ALD), which is a sequential CVD, allowing to build atomic layer by atomic layer, dense, homogeneous and conformal films of less than 1 µm. Our laboratory is one of the pioneers in this field. Ceria and zirconia-based layers interlayers have been processed successfully with different dopants, varying their structural and electrical properties. Moreover, ALD can be used also to process cathode materials, catalysts etc.

B0414

Triple Mixed e- / O2- / H+ Conducting (TMC) oxides as oxygen electrodes for H+-SOFC

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Abstract

High temperature protonic conductors have drawn an increasing attention during the last ten years. Currently, the development of Protonic Conducting Solid Oxide Fuel Cells (H^+-SOFC) is not only limited by the lack of a reference electrolyte but also by the need of cathode materials showing mixed H^+ / e^- conduction, unlike SOFC-O^{2-} for which MIEC (O^{2-} / e^-) oxides are efficiently used as cathode materials.
Indeed, a specific feature of H^+-SOFCs is that water is formed at the cathode side according to the reaction $½\ O_{2(g)} + 2H^+ + 2e^- \rightarrow H_2O_{(g)}$. The use of MIEC ($O^{2-}$ / e^-) materials restricts the water formation to a finite area where the cathode and the electrolyte are in close contact and limits the kinetics of the reaction that occurs into two steps.
The strategy that we adopted to obtain H^+ / e^- conducting oxides and to overcome this problem, has been to use a MIEC oxide with a sufficient oxygen vacancy concentration to allow hydration able to induce a possible protonic conduction. This work is devoted to the study of MIEC (O^{2-} / e^-) oxides ($La_{0.6}Sr_{0.4}Fe_{0.8}Co_{0.2}O_{3-\delta}$, $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$, $PrBaCo_2O_{5+\delta}$ and $Pr_2NiO_{4+\delta}$) well-known for SOFC application.
Their hydration properties were studied by TGA measurements performed under high pH_2O partial pressure in relation with their oxygen non-stoichiometry and electrochemical performances (polarization resistances and cathodic overpotentials). A careful attention was paid to the determination of the electrolyte/electrode and gas/electrode interfaces processes using EIS measurements under high pH_2O. Moreover, the influence of their physical properties (*i.e.* oxygen non-stoichiometry and electrical conductivity) on their electrochemical behaviour was also characterized and correlated to their transport properties. The study of the rate determining steps was carried out and In conclusion, the electrochemical behaviour of the MIEC oxides giving the best electrochemical performances was explained by the protonic conduction, giving rise to a new class of oxides, the Triple Mixed e^- / O^{2-} / H^+ Conducting oxides (TMCO).

B0415

$SrMo_{1-x}Fe_xO_{3-\delta}$ perovskites anodes for performance solid-oxide fuel cells

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Abstract

Oxides of composition $SrMo_{1-x}Fe_xO_{3-\delta}$ (x= 0.1, 0.2) have been prepared, characterized and tested as anode materials in single solid-oxide fuel cells, yielding output powers close to 900 $mWcm^{-2}$ at 850ºC with pure H_2 as a fuel. This excellent performance is accounted for the results of an "in-situ" neutron powder diffraction experiment, at the working temperature of the SOFC, showing the presence of a sufficiently high oxygen deficiency, with large displacement factors for oxygen atoms that suggest a large lability and mobility, combined with a huge metal-like electronic conductivity, as high as 340 $S{\cdot}cm^{-1}$ at T= 50ºC for x= 0.1. The magnitude of the electronic conductivity decreases with increasing Fe-doping content. An adequate thermal expansion coefficient, reversibility upon cycling in oxidizing-reducing atmospheres and chemical compatibility with the electrolyte make these oxides good candidates for anodes in intermediate-temperature SOFC (IT-SOFCs).

B0416

A study on structural, thermal and anodic properties of $V_{0.13}Mo_{0.87}O_{2.935}$

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Abstract

$V_{0.13}Mo_{0.87}O_{2.935}$ has never been previously studied as an anode material in Solid Oxide Fuel Cells. $V_{0.13}Mo_{0.87}O_{2.935}$ powder was obtained by reducing acidified vanadate and molybdate solution at 60 ºC by passing hydrogen sulfide gas through the solution. The obtained multicomponent mixed oxide was investigated by scanning electron microscopy (SEM), X-ray diffraction (XRD) and thermal analysis (TG/DTA).

$V_{0.13}Mo_{0.87}O_{2.935}$ powders were mixed with ethyl cellulose and terpineol at a similar ratio to prepare the anode screen printing paste. The paste was then screen printed on the surface of the $((Y_2O_3)_{0.08}(ZrO_2)_{0.92})$ (YSZ) electrolyte with 30 mm diameter and sintered at 850 ºC for 2 h. $((La_{0.60}Sr_{0.40})(Co_{0.20}Fe_{0.80})O_{3-\delta})$ (LSCF) was used as a cathode material and the obtained solid oxide fuel cell was tested for the temperatures of 700, 750 and 800 °C and the maximum values of 0.38 ± 0.06 A/cm^2 and 0.18 ±0.03 W were respectively obtained as current density and power at 800 °C in the cell.

B0418

Low Temperature Preparation of LSGM Electrolyte-based SOFC by Aerosol Deposition

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Abstract

$(La,Sr)(Ga,Mg)O_{3-\delta}$ (LSGM) electrolyte based solid oxide fuel cells (SOFCs) were aerosol deposited on conventionally sintered NiO-GDC anode substrates at room temperature to minimize reactions between them. Composite cathodes comprising $(La,Sr)(Co,Fe)O_{3-\delta}$ (LSCF) and polyvinylidene fluoride (PVDF) were similarly deposited at room-temperature. Both electrolytes and cathode maintained good adhesion. The cell containing LSGM electrolyte and LSCF cathode showed open cell voltage of ~1.1 V and maximum power density of ~1.2 W/cm^2 at 750°C. Post-annealing of the electrolyte/anode bi-layer decreased the open cell voltage due to the interfacial reaction. The peak power density of the cell was increased with annealing of 1000°C probably due to the grain growth of electrolyte layer, and decreased with annealing at 1200°C, representative of temperatures during conventional cell fabrication, due a reduction of OCV by severe Ni diffusion and increased electronic conductivity. We have shown that aerosol deposition is a promising technique to decrease the fabrication temperature and to optimize the performance of LSGM electrolyte-based SOFCs.

B0420

Electrochemical Study of Nano-composite Anode for Low Temperature Solid Oxide Fuel Cells

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Abstract

The entire world is conscious to find out alternate renewable energy source due to rapidly depletion of fossil fuels. Solid oxide fuel cells are one the best alternative energy source but the investigation new Ni free electrode material for low temperature solid oxide fuel cell is a great challenge for fuel cell community. For this purpose, nano-composite anode materials of Ba0.15 Fe0.10Ti0.15Zn0.60 (BFTZ) were successfully synthesized by solid stated reaction method. Their crystal structure and surface morphology was investigated by XRD and SEM, respectively and particle size was found to be 39 nm. The (BFTZ) anodes were tested in fuel cell with ceria-alkali carbonates composite NKCDC electrolytes and BSCF conventional cathode. The fuel cell was fabricated by dry press technique with 13mm in diameter. The maximum power density was achieved to be 471mW/cm2 550oC. Electrical conductivity was found to be 5.86 and 4.81S/cm at 600oC in hydrogen atmosphere by DC and AC approach respectively.

B0421

Electrochemical performance of the perovskite-type $Pr_{0.6}Sr_{0.4}Fe_{1-x}Co_xO_3$

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Abstract

Solid oxide fuel cells (SOFC) are one of the most promising energetic devices for environmentally clean power generation. Many materials have been studied for their application as SOFC cathodes, being the orthoferrites and cobaltites the most promising ones.

The mobility of the oxide ions highly influences the performance of this type of fuel cells. In solid oxide materials, oxygen ions are transported by the random hopping of oxygen vacancies in the anion framework of the materials. These oxygen vacancies are formed by charge imbalances caused by the doping of the materials. Therefore, in this work the influence of the Co content in the B site of the perovskite type $Pr_{0.6}Sr_{0.4}Fe_{1-x}Co_xO_3$ (x = 0.2, 0.4, 0.6, 0.8) oxide has on the electrochemical performance of the cathode is studied.

Powders of $Pr_{0.6}Sr_{0.4}Fe_{1-x}Co_xO_3$ (PSFC) were prepared according to the conventional liquid-mix route. Commercial substrates of yttria stabilized zirconia (YSZ) have been employed as electrolyte due to its excellent stability at the operating temperatures and conditions.

The crystalline powders were characterised by X ray powder diffraction data and scanning electron microscopy (SEM). Due to their important mechanical effects the thermal expansion coefficients (TECs) of the obtained materials were also analyzed. The electrochemical behaviour of the samples was determined by Electrochemical Impedance Spectroscopy (EIS) measurements of symmetrical PSFC/YSZ/PSFC cells performed at equilibrium from 850 ºC down to room temperature, under both zero dc current intensity and air.

B0422

Effect of Composition Ratio of Ni-YSZ Anode on Distribution of Effective Three-Phase Boundaryand Power Generation Performance

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Abstract

The electrode microstructure of SOFCs has a significant influence on the power generation performance. Therefore, it is important to find the quantitative relationships between the electrode microstructure and the performance for improving SOFCs. The focused ion beam and scanning electron microscope (FIB-SEM) is a powerful mean to directly observe the 3D microstructure of the porous electrodes. From the obtained 3D structure, we can precisely evaluate many microstructural parameters, such as three-phase boundary (TPB) density, phase connectivity and tortuosity factor. Such parameters are considered as the keys to optimizing the electrode microstructure for achieving high performance electrode.

Commonly-used electrode materials, such as Ni-YSZ cermet, consist of two solid phases: electron-conductive phase and ion-conductive phase. Therefore, the composition ratio of the two materials is the primary control parameter to optimize the microstructure. Generally, the electrode performance depends on the two aspects: TPB density and phase connectivity. Since the electrochemical reaction in the electrode is considered to occur at TPB, electrodes should contain as much TPB as possible. Also, the phase connectivity of each phase should be secured for the sufficient transport through the phases. Therefore, it is important as a first step to clarify the influence of the composition ratio on the above-mentioned parameters. The knowledge obtained through the microstructural analysis is useful for correlating the microstructure and the electrode performance.

In this study, first we experimentally evaluate the electrochemical performance of Ni-YSZ anodes with three different composition ratios: Ni:YSZ = 70:30, 50:50 and 30:70 vol.%. Next, we observe the 3D microstructure of the anodes with FIB-SEM, and quantify the microstructure of the porous anodes. The TPB distribution and phase connectivity inside the anodes are investigated. Finally, we conduct a 3D numerical simulation of the anode overpotential using the observed microstructure. The analysis is based on the finite volume method (FVM), and considers the electron transport in the Ni phase, ion transport in the YSZ, gas diffusion in the pore phase and the electrochemical reaction at TPB. Combining the microstructural investigation and the numerical analysis, the effect of the composition ratio on the electrode performance is discussed focusing on the reaction region inside the anodes.

B0423

Effect of Sr Content Variation on the Performance of $La_{1-x}Sr_xCoO_{3-\delta}$ Thin-film Cathodes Fabricated by Pulsed Laser Deposition

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Abstract

In order to compare the influence of Sr contents of $La_{1-x}Sr_xCoO_{3-\delta}$ (LSC) cathodes on the cell performance, we selected two LSC compositions having Sr contents of x = 0.4 (LSC64) and x = 0.2 (LSC82). LSC64 and LSC82 cathode layers were fabricated by using pulsed laser deposition (PLD), on an anode-supported cell with an yttria-stabilized zirconia (YSZ) electrolyte and a gadolinia-doped ceria (GDC) buffer layer. The fabrication temperature did not exceed 650°C. Current-voltage curves and electrochemical impedance spectra were measured at operation temperatures of 650°C ~ 550°C. According to the results, the performance of the LSC64 cell is much superior to that of the LSC82 cell. This performance difference basically originated from the difference of the number of oxygen vacancies which affect the cathodic properties, especially the oxygen surface exchange. In terms of the performance drop by decreasing the operating temperature, that of the LSC64 cell is less than that of the LSC82 cell as well. In the current presentation, the impedance analysis for the electrode reaction mechanism and cell performance comparisons will be discussed in more detail.

B0424

Nanostructure Gd-CeO_2 LT-SOFC electrolyte by aqueous tape casting

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Abstract

An aqueous tape casting of gadolinia-doped ceria ($Ce_{0.9}Gd_{0.1}O_{1.95}$, GDC) electrolyte was fabricated for low-temperature (LT) operating solid oxide fuel cells (SOFCs). The ceramic powder prepared by combustion synthesis was used with poly acrylic acid (PAA), poly vinyl alcohol (PVA), poly ethylene glycol (PEG) and double distilled water as dispersant, binder, plasticizer and solvent respectively, to prepare stable GDC slurry. The conditions for preparing stable GDC slurries were studied and optimized by sedimentation, zeta potential and viscosity measurements. Tape casting was achieved using a laboratory-scale machine with a moving Mylar substrate film. A casting speed of 100 mm/min and a doctor blade gap height of 1mm were chosen. After tape casting, the casted tapes were dried at room temperature. The thickness of green tapes was in the range of 0.35–0.4 mm. Sintering was done in air at 1350ºC for 5h. Microstructure results showed smooth and defect-free surface of electrolyte tapes with nano-scale grains.

B0426

Evaluation of MoNi-CeO_2 Cermet as IT-SOFC Anode using ScSZ, SDC and LSGM electrolytes

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Abstract

The present work studies the bimetallic Ni-Mo formulation combined with CeO_2 as its potential use as anode material for intermediate solid oxide fuel cell (IT-SOFC). This compound was synthesized by coprecipitation within reverse microemulsion method with a nominal chemical formula of $Ce_{0.7}Ni_{0.25}Mo_{0.05}O_{2+\delta}$ (MoNi-Ce) and presented a fluorite phase of CeO_2 together with a second cubic phase of NiO. After its reduction in 10% H_2 at 750°C for 50 h, the fluorite type structure was retained and diffraction peaks due to metal nickel were detected. X-ray photoelectron spectroscopy (XPS) revealed the presence of Mo^{6+} and NiO in the oxidized sample and the coexistence of Ni^0 and Ni^{3+} as well as Mo^{5+}, Mo^{5+}, Mo^{4+} and Mo^0 after its reduction. The thermal expansion coefficients (TEC) were 11.6 in air and 12.3 $x10^{-6}$ K^{-1} (200-450°C) and 11.5 $x10^{-6}$ K^{-1} (450-750°C) in reducing atmosphere. These values are close to that of the other SOFC cell components (10-13 $\times 10^{-6}$ K^{-1}). This compound showed a semiconductor behavior with an activation energy of 0.97 eV and the maximum electrical conductivity value was of 0.3 $S \cdot cm^{-1}$ at 750 °C in dry 10% H_2. Its electrical conductivity drops with increasing pO_2 values indicating a *n*-type electronic conduction. Reactivity studies between this material and ScSZ (10% mol Sc_2O_3 stabilized ZrO_2), SDC ($Sm_{0.2}Ce_{0.8}O_{2-\delta}$) and LSGM ($La_{0.9}Sr_{0.1}Ga_{0.8}Mg_{0.2}O_{3-\delta}$) electrolytes were investigated by mixing equal amount of anode material and electrolyte powder. The mixtures were fired in 10% H_2 for 50 h at 750 ºC. XRD patterns demonstrated that no chemical reaction occurred between MoNi-Ce and electrolyte materials, no new phases or changes were observed. The electrochemical characterization of this anode material using ScSZ, SDC or LSGM as electrolytes was studied by impedance spectroscopy (IS) using symmetrical cells (MoNi-Ce/electrolyte/MoNi-Ce). The IS measurements were carried out as a function of temperature (550-750 °C) in dry 10%H_2/N_2 and wet CH_4 using a signal amplitude of 5 mV at open circuit from 100 KHz to 10 mHz. The best performance was obtained with SDC as electrolyte with area specific resistance (ASR) values of 0.76 and 0.16 $Ohm \cdot cm^2$ at 750 °C in dry H_2 and wet CH_4, respectively.

B0427

Investigation of the electrochemical stability of Ni-infiltrated porous YSZ anode structures

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Abstract

Infiltration of SOFC electrodes has been shown to be a very promising method in terms of forming a uniform and continuous network of nanoparticles in a porous backbone. Moreover, this method has introduced a possible solution for Ni-based anode redox problems by lowering the Ni content needed to reach adequate electronic percolation. It can also lead to a better anode microstructure by producing smaller Ni particles, resulting in higher triple phase contact areas between the anode and the electrolyte, and consequently, better electrochemical cell performance. Furthermore, as any high temperature sintering process usually takes place before the infiltration step, a range of other temperature-sensitive anode and cathode materials can be examined using this method. Unfortunately, Ni particle sintering during cell testing can be severe, and efforts are underway to impregnate secondary ceramic phases, such as MgO, Al2O3, TiO2, CeO2 and GDC, as anti-sintering aids.
Our research centers on combining the advantages of a tubular cell configuration in terms of thermal stress tolerance and ease of sealing with the use of infiltration methods to incorporate new anode materials. Our preliminary work has investigated infiltrated Ni as the current collector within the anode support layer, to assess its relative stability during cell operation. Using two-electrode studies of symmetrical Ni-YSZ half-cells with thin YSZ electrolyte, combined with bulk conductivity and structural imaging techniques, we are determining the structural changes that specifically lead to anode performance degradation with time. As expected, the electrochemical results (galvanostatic and impedance spectroscopy) show significant cell degradation with time, especially compared to analogous dense YSZ electrolyte-supported and Ni/YSZ cermet-supported samples. This presentation will describe our methods of differentiating the degradation mechanisms and our attempts at minimizing this effect through co-impregnation of ceria compounds.

B0428

High Electrochemical Performance of Mesoporous NiO-CGO as Anodes for IT-SOFC

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Abstract

High operating temperatures put numerous requirements on materials selection and on secondary units of solid oxide fuel cells (SOFCs). For this reason, lowering the operating temperature to the intermediate range (600–800 ºC) has become one of the main research goals toward the commercialization of these devices.
In particular, the microstructure of the anodes plays a key role in the performance as it is critical for the establishment of the required three-phase electrochemically active zone.
In this work, the objective of having high surface area with thermally stable structures is achieved by using mesoporous Ni-based anodes, in particular nickel oxide-gadolinia doped ceria (NiO-CGO).
A mesoporous silica template KIT-6 was used, exploring the influence of its morphology on the replication process.
Highly stable mesoporous cermets (NiO-CGO) were synthesized up to 1100ºC. This high stabilization temperature plays an important role for the subsequent attachment process to the electrolyte. A comprehensive structural analysis was carried out in order to characterize the mesoporous oxide and to confirm the correct infiltration and the stability of the composites.
The electrochemical performance of the anodes was measured in a symmetrical cell configuration (Ni-CGO/CGO/Ni-CGO) in humidified 5%H_2 in N_2 atmosphere and in pure hydrogen. Targeted values of Area Specific Resistance (ASR) of 0.25 ohm·cm^2 were obtained in the intermediate range, showing the suitability of implementing this route as a general methodology to synthesize other materials as electrodes. One symmetrical cell was subjected to real operating conditions (800ºC) for more than 200 hours showing stability and no degradation.
The mesoporous materials were (micro)structural analyzed after the electrical measurements confirming the stability of the mesostructure after the operating conditions. The here-presented mesoporous approach shows a new class of highly stable nanostructured electrodes for intermediate temperature solid oxide fuel cells.

B0429

Synthesis of Lanthanum Silicate Oxyapatite by Using Na2SiO3 Waste Solution as Silica Source

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Abstract

In recent years, lanthanum silicate oxyapatites ([$Ln_{10-x}(XO_4)6O_{3-1.5x}$] (X=Si or Ge)) have been studied for use in SOFC (Solid Oxide Fuel Cells) due to its ionic conductivity, at low temperature (600-80°C), which is higher than that of YSZ (Yttrium Stabilized Zirconia) electrolyte. It is one promising candidate as the solid electrolyte for intermediate-temperature SOFCs. Synthesis of functional nanoparticles is a challenge in the nanotechnology. In this work, lanthanum silicate oxyapatite nanoparticles were synthesized by chemical precipitation of lanthanum hydroxide on porous silica nanoparticles followed by heat treatments. Na_2SiO_3 waste solution was used as silica source; HCl was used for preparing silica spherical aerogel. The obtained powders of oxyapatite were characterized by thermal analysis (TGA-DTA), X-ray diffraction, scanning electron microscopy (MEV) and specific surface area measurements (BET). The oxyapatite phase may be obtained at 900°C.

Key words: synthesis, SOFC, oxyapatite, electrolyte

B0431

Prospects and Challenges of the Solution Precursor Plasma Spray Process to Develop Functional Layers for Fuel Cell Applications

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Abstract

The Solution Precursor Plasma Spraying (SPPS) enables in-flight pyrolysis of the feedstock precursors to generate the finished powders or directly the coating of desired chemistry. As production process, it offers the synthesis of nano-sized materials, particularly coatings, without the disadvantages of handling and manipulation of nano-scale feedstock powders. New precursor compositions can be realized in an easy and fast manner and can be tested without the need of plasma sprayable powders. Furthermore, adjustment of spraying parameters can avoid problems such as chemical decomposition of materials due to the high temperature as described in literature during sintering of Barium cerates. For each coating, however, a relationship between process, microstructure and property should be defined. Depending on time-temperature history of the droplets in the plasma the properties of resultant deposits are ranging from ultra-fine splats to unmelted crystalline particles and unpyrolized particles, which should be controlled in order to attain appropriate microstructure.
In the current work, thermo-decomposition of precursor complexes by the thermal plasma spray process was utilized to synthesize different classes of materials. Using aqueous or water-ethanol solutions of zirconium salts, zirconia-based coating were developed for it potential use as electrolyte and anode material for Solid Oxide Fuel Cells (SOFCs). Solution characteristics and process parameters were correlated to the structural properties for the coatings. It was established that the higher ethanol content in the solvent led to improved in-flight pyrolysis and lower porosity of the precursors.
In later trials, similar experiments were conducted for development of a composite layer of oxygen ion conducting yttria doped ceria (YDD) and yttria doped barium cerate (BCY). The composite layer was developed for an innovative fuel cell concept for intermediate temperature applications and is running under the FP7 European project “IDEAL-Cell”. A mixture of BCY and YDC is used for the porous central membrane where the hydrogen ion react with oxygen ions to form water. Ceramic layers, such as BCY or YDC and BCY / YDC dual-layers, obtained by the SPPS process were characterized according their microstructure by X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX), scanning electron microscopy (SEM), and Raman spectroscopy. Results of SPPS process and characterization of deposits will be presented. The arc current and the enthalpy of the plasma were found to be the major parameters determining the composition of the layers as well as the deposition rates and microstructure.

B0432

Tailoring SOFC cathodes conduction properties by Mixed Ln-doped ceria/LSM

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Abstract

Lanthanide substitute ceria are emerging candidates for solid oxide fuel cells/electrolyzers as they combine high oxygen-ion mobility, redox catalytic properties and chemical compatibility with water and carbon dioxide at high temperatures. In this work, a series of doped cerias including Gd, La, Tb, Pr, Eu, Er, Yb has been prepared and characterized in order to obtain an overall understanding of the structural and transport properties of these materials. The chosen lanthanides included a large range of ionic radii and different metals exhibiting variable oxidation state under the typical operating conditions for these materials, so they can provide either mainly ionic or mixed ionic and electronic conductivity (MIEC) [1] over the studied pO_2 range.

Lanthanide substituted cerias were mixed with the state of the art strontium doped lanthanum manganite ($La_{0.85}Sr_{0.15}MnO_3$ - LSM) cathode, which is a pure electronic conductor, in order to provide ionic conductivity and increase the triple phase boundary (TPB) area.

The doped cerias have been characterized by powder XRD, μ-Raman spectroscopy, DC conductivity, and different composition – structure relationships have been identified [2]. The electrochemical behavior for the different oxygen electrodes, based on modified ceria materials mixed with LSM powder, has been tested by means of EIS measurements performed on symmetrical cells based on CGO82Co dense electrolytes as a function of temperature and oxygen partial pressure.

All the composites improved the performance of the parent LSM cathode since the ceria phase introduces ionic conductivity and increases the TPB area. Nevertheless, the best results were obtained when cerias exhibiting mixed ionic and electronic conductivity were employed. Thus the functionality of these materials as SOFC cathode component has been proved for some compositions. Finally, the electrochemical behavior of the different composite electrodes is discussed on the basis of the equivalent circuit results.

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[1] Balaguer M.; Solís C.; Serra J.M., *Chem. Mater.* **2011**, submitted.

B0433

In-plane and across-plane electrical conductivity of RF-sputtered GDC film

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Abstract

Micro-SOFC is required to power small electronics such as smart phones and notebook computers. An electrolyte with high electric conductivity is highly required for micro-SOFC which may operate at low (<~500°C) temperature. Thin film electrolyte with highly conductive versus conventional yttrium-doped zirconia is required but has not been studied in detail. In this study, we have studied whether the electrical conductivity of Gd-doped ceria (GDC) thin-film is suitable for micro-SOFC. GDC thin films were deposited by RF magnetron sputtering on glass substrate or on porous-metal coated on glass substrate. Conductivities of the films were measured either in “in-plane mode” (parallel to film plane) or “across-plane mode” (perpendicular to film plane) in various oxygen partial pressures (Po_2) at 300, 350, 400°C. Scanning electron microscopy, X-ray diffraction, electrochemical impedance spectroscopy revealed that films deposited on glass substrate showed columnar grains and the higher electronic conductivity and the lower ionic conductivity than those of bulk. However, highly oriented film deposited on sapphire substrate showed few grain boundaries and exhibited similar or higher ionic conductivity than bulk. Conductivities measured across film plane also showed the similar trend with negligible grain boundaries.

B0434

High Energy Ball Milling for dense GDC barrier layers

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Abstract

A Gadolinia Doped Ceria (GDC) dense barrier between electrolyte and Lanthanum Strontium Cobalt Ferrite cathode is required to overcome chemical incompatibility issues in IT-SOFC technology. GDC particles dispersed in stable suspensions (inks) are required to obtain this FC component by Screen Printing technique. After printing, a thermal sintering process is applied to consolidate the ceramic powder.
However, inks characterised by mono-modally distributed particles do not guarantee a sufficiently dense barrier layer.
High Energy Ball Milling (HEBM) technology has been applied to obtain GDC nanoparticles starting from commonly available commercial material. The preliminary results demonstrate the effectiveness of the mechanical-chemical process in reducing material size. The obtained powders consist of nanoparticles having a diameter of ~ 30 nm composed of multiple crystalline domains of ~17 nm.
Bimodal distributed inks have been obtained by simply mixing the obtained nanomaterial with standard commercial powders.

B0436

Investigation of Catalytic Properties of Machanochemically Prepared Strontium-Doped Nanostructural Lanthanum Manganit

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Abstract

The fuel cells (FC) are distinguished as generating of distributed energy and are electrochemical devices of low environmental impact. In this work, the strontium-doped lanthanum manganite, a ceramic material used as cathode in solid oxide fuel cells (SOFCs). Currently, the great interest of the researchers to this material has been the study of its characteristics, such as: good chemical and thermal stability, high catalytic activity in the oxygen reduction reaction, thermal expansion coefficient similar to the electrolyte (yttria stabilized zirconia) and high electrical conductivity.
The nanocrystalline $La_{0.8}Sr_{0.2}MnO_3$ (LSM) is prepared by varying the milling time of planetary monomill during the mechanochemical method. After that the ground LSM powder was applied to dense YSZ electrolyte pellet by print-screen method and sintered at 1300 $_oc$ for 4 hr. The Gas Chromatography test was used in order to study the catalytic activity of porous LSM cathode material in methane gas conversion . For investigate the volume percent, size and distribution of porosities Secondary Electron microscopy (SEM) imaging was utilized. The results of this research confirmed that by increasing grinding time as an important factor in LSM mechanochemical synthesis, the catalytic characteristics as well as pore distribution is modified.

B0501

Stroboscopic Ni Growth/Volatilization Picture

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Abstract

Ni growth- and volatilization-induced changes in the microstructure of solid oxide fuel cell (SOFC) Ni-$(Ce_{0.6}Gd_{0.4})O_{2-\delta}$ (Ni-CGO) anodes are revealed in this work by image analyses from dual scanning electron microscopy (SEM) - focused ion beam (FIB) acquisitions as well as by energy-dispersive X-ray spectroscopy (EDS).
Single layer cermet anodes with high Ni content exposed to 2% H_2O at 900°C are subjected to grain coarsening of both Ni and CGO phases, as revealed by image segmentation and analysis of FIB-polished cross-sections. On the one hand, low-voltage SEM imaging of such surfaces free of preparation artifacts enables accurate and localized characterization of morphological parameters. High-energy EDS provides on the other hand an averaged but precise measure of the composition of such microstructures. Only minor loss of Ni is discerned in such dry exposure conditions substantiating the stable electronic conductivity assessment over 3'000 h.
The EDS methodology developed here to reveal small changes in microstructure compositions was applied on double-layered Ni-CGO fuel electrodes exposed to moist conditions (60% H_2O and 950°C) over 2'286 h. The nickel fraction decreases within the functional anode, where Ni particles are small, whereas remaining constant in the coarse current collector, indicating the Ni loss to depend on the initial microstructural features. Severe Ni loss is believed to be caused by Ni volatilization at high humidity to hydrogen ratio/flux.
Indeed, post-mortem depiction of a Ni-based anode support after 10'000 h testing at 750°C and 73% fuel utilization disclose Ni volatilization where the local steam concentration is high. Ni loss is observed in electrochemically active anode regions near the electrolyte, whereas remaining constant in the anode support.
Both accurate (FIB) and precise (EDS) techniques combined, the evolution of Ni-based anodes is objectively depicted by time-lapse SEM photography of 8, 4 and 1 samples withdrawn from 2'286, 3'000 and 10'000 h exposure tests, respectively. This approach yields microstructural parameters as modeling input for life-span estimations at the 40'000 operating-life prerequisite for stationary SOFC application.

B0502

Oxidation of nickel in solid oxide fuel cell anodes: A 2D kinetic modeling approach

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Abstract

Multiple mechanisms of performance degradation impact the lifetime of solid oxide fuel cells (SOFC). One issue regarding the commonly used Ni/YSZ composite anodes is nickel oxidation. The formation of nickel oxide (NiO) can cause performance losses due to triple phase boundary (TPB) reduction. Moreover the volume expansion during the Ni/NiO transition can block the free pore space and cause mechanical fractures.
To achieve a deeper understanding of the processes leading to nickel oxidation, two possible reaction pathways were integrated into a 2D SOFC model. The model includes coupled electrochemistry and transport through MEA and gas channels. A multi-phase management allows for quantifying the evolution of nickel and nickel oxide inside the anode. Oxidation of nickel is firstly implemented as a thermochemical reaction, with free oxygen or water vapour inside the fuel gas acting as oxidant:

$$Ni + \tfrac{1}{2} O_2 \rightleftharpoons NiO \quad \text{and/or} \quad Ni + H_2O \rightleftharpoons NiO + H_2 \ .$$

Additionally we regard electrochemical nickel oxidation, where oxygen ions diffusing through the electrolyte reduce the nickel metal, releasing free electrons:

$$Ni + O^{2-} \rightleftharpoons NiO + 2\,e^- \ .$$

The feedback between nickel oxidation and cell performance is modeled by taking into account both, a loss in kinetic performance (via reducing three-phase boundary length) and a reduction in gas-phase diffusivity (via porosity decrease upon solid volume expansion).
The simulation allows the spatially resolved prediction of nickel oxide formation over time and its influence on cell performance under arbitrary operation conditions. Here we predict the occurrence of a second plateau as well as a loop in the polarization curve of a SOFC, caused by electrochemical oxidation of nickel.

B0503

Nickel oxide reduction studied by environmental TEM

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Abstract

In situ reduction of a commercial NiO powder is performed under 1.3 mbar of H_2 (2 ml_N/min) in a differentially pumped FEI Titan 80-300 environmental transmission electron microscope (ETEM). Images, diffraction patterns and electron energy-loss spectra (EELS) are acquired to monitor the structural and chemical evolution of the system during reduction at different temperature ramps (at 2, 4 and 7°C/min). High-resolution ETEM is also performed during similar experiments.
Ni nucleation on NiO is observed to be either epitaxial in thin areas or randomly oriented on thicker regions and when nucleation is more advanced. The growth of Ni crystallites and the movement of interfaces induce particle shrinkage and the creation of pores within the NiO grains to accommodate the volume shrinkage associated with the reduction. EELS analysis illustrates that reduction proceeds quickly at temperatures below 400°C up to a reduced fraction of about 0.6, until the reaction is slowed down by water created upon reduction. Using the data obtained at different heating rates and the Kissinger method, an activation energy for the NiO reduction of 70 ± 20 kJ/mol could be obtained. Densification is then observed at temperatures higher than 550°C: pores created at lower temperatures disappear and Ni grains coarsen. This reorganization of Ni is detrimental to both the connectivity of the Ni catalyst and the redox stability of the SOFC. A model for the structural evolution of NiO under H_2 is proposed.

B0504

LEIS of Oxide Air Electrode Surfaces

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Abstract

The bulk properties of the functional materials for SOFC's and SOEC's have been studied for many years and we have a good understanding of how the basic defect properties relate to the important transport phenomena central to the operation of these devices. This is far from the case when the surfaces of these materials are being considered. Even though it is well understood that surfaces are critical to the development of both devices, it is not until recent years that experimental and theoretical effort has begun to increase in this important area. This is particularly important for the air electrode of these devices where effects such as segregation of impurities and additives, corrosion products, chromium poisoning, and depletion of volatile components can limit the oxygen flux across the surface of the electrode under working conditions.

Low Energy Ion Scattering (LEIS) is a technique that gives quantitative information about the composition of the outermost atomic layers of oxide materials. When this compositional information is coupled with the measured oxygen exchange kinetics it can provide insights into the interplay of the effects mentioned above, such as segregation, on the oxygen exchange process.

In this paper, details will be given of the LEIS measurement technique and the application to oxide materials that have been proposed for roles as air electrodes, including the double perovskite $GdBaCo_2O_{5+\delta}$.

B0505

Impact of Surface-related Effects on the Oxygen Exchange Kinetics of IT-SOFC Cathodes

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Abstract

The oxygen exchange kinetics is a key parameter which determines the performance of solid oxide fuel cell (SOFC) cathodes. The cathodes should retain both a high oxygen reduction activity and a sufficient stability during the targeted life-times of SOFC systems of 5,000-40,000 h under real operating conditions. In the present study the chemical surface exchange coefficients (k_{chem}) and the chemical diffusion coefficients of oxygen (D_{chem}) of the mixed ionic-electronic conducting cathode materials $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ (LSC) and $La_{0.58}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF) are determined by in-situ conductivity relaxation experiments at 600°C during 1000 h periods. A 2D finite element model is used to predict the area-specific resistance (ASR) of LSC cathodes with different microstructures. Systematic variations of the testing conditions (dry or humidified atmospheres, absence or presence of impurity sources) are performed, and the impact on the kinetic parameters and the cathode ASR is discussed. Changes in the surface-near chemical composition, which are correlated to a decrease in the oxygen reduction activity, are shown to occur even during 1000 h under highly pure laboratory conditions. Under real operating conditions the degradation is more severe, especially under humid conditions, due to the enhanced gas phase transport of volatile impurities (Cr and/or Si). High-resolution scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), and transmission electron microscopy (TEM) are applied in order to gain further insight into the correlated changes of the cathode surface chemistry and microstructure. It can be concluded that, even though these effects are limited mostly to surface layers in the range of 10-100 nm thickness, they can induce a strong decrease in the cathode performance.

B0506

Anisotropy of the oxygen diffusion in $Ln_2NiO_{4+\delta}$ (Ln=La, Nd, Pr) single crystals

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Abstract

$Ln_2NiO_{4+\delta}$ (Ln = La, Pr or Nd) rare-earth nickelate oxides are considered promising oxygen electrode materials for IT-SOFCs due to their aptitude to accommodate oxygen over-stoichiometry leading to Mixed Ionic-Electronic Conducting (MIEC) properties. Their ability to incorporate extra oxygen and of the oxide ions to diffuse at intermediate temperatures has been previously shown for polycrystalline materials. Knowledge of the relevant oxygen transport parameters (oxygen transport coefficients D^* and surface exchange constants k^*) in such oxides is of fundamental importance, especially for understanding the oxygen transport mechanisms in these materials with anisotropic structural properties. By experimentally tracing the isotopic oxygen ion concentration as a function of depth (Isotopic Exchange Depth Profiling technique) and solving the corresponding analytical equation, these two coefficients can be determined. Such a method has been used to perform measurements on single crystals carefully oriented along the two main directions (*ab* plane and *c*-axis). The measurements were performed between 450 and 600 °C.
Large single crystals (size ~ 1cm) of these rare-earth nickelates ($La_2NiO_{4+\delta}$, $Pr_2NiO_{4+\delta}$ and $Nd_2NiO_{4+\delta}$) were successfully grown using the so-called Floating Zone technique (FZ) in the temperature range 1700-1800 °C. While the melting of $La_2NiO_{4+\delta}$ is congruent, for the two other compounds an excess of NiO was added in order to get the stoichiometric chemical composition.
From the IEDP results, as expected from a crystallographic point of view, anisotropy of both the surface exchange and the diffusion coefficients have been observed for the three compounds. The anisotropy ratio of the oxygen bulk diffusion is about two orders of magnitude.

B0508

3-D Multi-scale Imaging and Modelling of SOFCs

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Abstract

Solid Oxide Fuel Cells (SOFC) are functional devices where performance is dependent on reactions in the porous electrode microstructures. Their complexity is often inadequately described using 2-D imaging especially as materials characteristics are linked to percolation. Furthermore, during both processing and operation, microstructural evolution occurs which may degrade electrochemical performance. Tomographic techniques are valuable tools in characterising electrode geometries allowing for the investigation of complex 3-D microstructures across a range of length scales.

In particular, focused ion beam (FIB) and X-ray nano computed tomography (nano-CT) techniques have been especially valuable for characterisation of electrodes, facilitating analysis of shape, structures and morphology at micro/nano scale resolution. Nano-CT is uniquely non-destructive at this length scale, enabling studies of microstructural evolution processes associated with electrode aging and degradation.

Tomography techniques are powerful when utilised in conjunction with modelling tools to provide understanding into diffusion, electrochemistry and stresses. This combined modelling and experimental approach can help in establishing structure/performance relationships providing key insights important for future fuel cell design. Here we present the results from multi-length scale x-ray and FIB tomography, coupled with results from modelling.

B0509

Synthesis and *In Situ* Studies of Cathodes for Solid Oxide Fuel Cells

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Abstract

Key to achieving the desired temperature reduction in SOFCs is the understanding of redox processes occurring at the cathode. It is expected that with better understanding new materials can be designed with properties more suited to the IT-SOFC range. With this in mind there is a clear requirement for techniques that can study redox process *in situ*. X-ray Absorption Near-Edge Structure (XANES) was chosen to study the IT-SOFC cathode materials $La_2NiO_{4+\delta}$ and $La_4Ni_3O_{10-\delta}$. For nickel the K-edge is in an energy region accessible by use of synchrotron radiation and using this nickel K-edges for $La_2NiO_{4+\delta}$ and $La_4Ni_3O_{10-\delta}$ at room temperature were found to be 8346.1 and 8347.2 eV. In order to assign these to an oxidation state the K-edges of compounds of known nickel oxidation state were found and used to create a calibration curve. Using this, the oxidation states of $La_2NiO_{4+\delta}$ and $La_4Ni_3O_{10-\delta}$ were found to be 2.24 and 2.58. These values were correlated with the defect chemistry of the two materials to give insight into the mechanism of charge-compensation for oxygen non-stoichiometry and an estimate of δ was obtained.

Further data were collected on $La_2NiO_{4+\delta}$ and $La_4Ni_3O_{10-\delta}$ whilst heating *in situ*. It was observed that the nickel oxidation state was reduced in both materials to 2.15 and 2.42 respectively. This indicates a changed δ and therefore gives insight into how their ionic conductivity may change under conditions similar to an operating IT-SOFC. Materials belonging to the $La_2Co_{1-x}Ni_xO_{4+\delta}$ solid solution were also studied; it was demonstrated that the X-ray absorption and hence redox chemistry of two different transition metal elements can be probed in the same material.

B0510

Quantification of Ni/YSZ-Anode Microstructure Parameters derived from FIB-tomography

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Abstract

A three-dimensional microstructure reconstruction aiming for quantification of two-phase electrode microstructures is presented, which is based on focused ion beam tomography. An in-depth knowledge of the Ni/YSZ anode microstructure is essential to understand and improve cell performance and life time.
By using image processing, the 3-D microstructures of Ni/YSZ anodes are reconstructed from a series of 2-D scanning electron microscope images. The whole process of reconstruction is investigated stepwise and sources of error are identified. Furthermore, a newly developed method for the accurate segmentation of two-phase materials is presented, which belongs to the *region growing* image segmentation methods.
Critical microstructure parameters like material fractions, triple-phase boundary density, surface areas, phase connectivity, particle size distribution, etc. are evaluated and discussed.
In this contribution, two different Ni/YSZ anode types are reconstructed and compared to each other. The presented methods are capable to quantitatively compare different electrode microstructures and relate the result to their electrochemical performance.

B0511

Evolution of Microstructural Parameters of Solid Oxide Fuel Cell Anode during Initial Discharge Process

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Abstract

Solid Oxide Fuel Cell (SOFC) is expected as a promising power generation device in the near future because of its advantages such as high efficiency and fuel flexibility. However, degradation of SOFC anode is one of the major obstacles for commercialization. In this paper, we apply FIB-SEM reconstruction and numerical methods such as level set and lattice Boltzmann method to characterize the evolutions of microstructural parameters during initial 250 hours operation. Temporal variations of microstructural parameters such as triple phase boundary length, tortuosity factors, surface areas, contact angles and curvatures of Ni, YSZ and pore phases are quantified for initial, 100 and 250 hours discharged cells.

B0512

Cation Diffusion Behavior in the LSCF/GDC/YSZ System

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Abstract

The LSCF (porous)/GDC(dense)/YSZ(sintered) triplet was investigated to evaluate the effectiveness of a dense 10GDC as a diffusion barrier. Cation diffusion behaviour was investigated using XRD, SEM, EDX, and SIMS. Results show the $SrZrO_3$ formed along both the LSCF/10GDC and the 10GDC/8YSZ interfaces, and also within the 10GDC interlayer. Nonetheless, fine cracks were observed within the 10GDC interlayer. $SrZrO_3$ formation at the interface is attributed to the Sr and Zr grain boundary diffusion through the 10GDC interlayer. On the other hand, Sr surface diffusion, possibly taking place along the cracks walls, leads to $SrZrO_3$ formation within the 10GDC layer. These facts suggest that the Sr grain boundary diffusion cannot be avoided even though the dense 10GDC is used as a diffusion barrier layer.

B0513

Long-term Oxygen Exchange Kinetics of La- and Nd-Nickelates for IT-SOFC Cathodes

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Abstract

Reducing the operating temperature of SOFCs from the high-temperature regime of 800-1000°C to intermediate temperatures (IT) of 500-700°C is considered to be beneficial with respect to life-time concerns due to slower kinetics of the underlying degradation processes. However, lowering the operating temperature may also have adverse effects on the long-term stability by allowing the formation of detrimental secondary phases, like e.g. carbonates or hydroxides through reaction with CO_2 or water as minor constituents of air. Since alkaline earth ions, in particular Sr and Ba, are often involved in such kind of degradation reactions, alkaline-earth free cathode materials appear to be attractive. Rare-earth nickelates are an interesting alternative to perovskite compounds commonly used as cathode materials. Due to the K_2NiF_4-type crystal structure and the presence of interstitial oxygen defects, Sr-substitution is not necessary in nickelates to obtain appreciable oxygen ionic conductivity. In this work two promising undoped nickelate compounds $La_2NiO_{4+\delta}$ and $Nd_2NiO_{4+\delta}$ are compared with respect to their applicability as SOFC cathode materials. Their long-term stability in dry and humid atmospheres is evaluated at 700°C over a period of 1000 hours by monitoring changes in oxygen surface exchange kinetics. X-ray photoelectron spectroscopy (XPS) depth profiles of the immediate sample surface have been recorded at several stages of the degradation process to correlate changes in the oxygen surface exchange process with modifications of the surface composition.

B0701

Step-change in (La,Sr)(M,Ti)O_3 solid oxide electrolysis cell cathode performance with exsolution of B-site cations

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Abstract

A-site deficient, B-site doped perovskites with formula $(La,Sr)_{1-\alpha}(M,Ti)O_{3-\gamma-\delta}$ (M = Ni, Fe) were employed as solid oxide electrolysis cell (SOEC) cathodes. The introduction of B-site dopants led to a large increase in the number (δ) of oxygen vacancies ($V_o^{\bullet\bullet}$) formed under reducing conditions (wet 5%H_2/Ar, 900 °C), from δ = 0.001 for the parent material to δ = 0.040 and δ = 0.033 for Ni- and Fe-doped materials, respectively. During SOEC operation in 47%H_2O/53%N_2 at 900 °C, B-site dopant cations were exsolved irreversibly from the host lattice to form metallic and reduced oxide nanoparticles on the surface, which acted as electrocatalytic sites. This resulted in significant lowering of the activation barrier for steam reduction, with onset potentials lowered (absolutely) from – 1.19 V for the parent material to – 0.63 V and – 0.98 V for Ni- and Fe-doped materials, respectively. Furthermore, B-site doping led to an increase in relaxation frequency (ν^*) values associated with oxide ion (O^{2-}) diffusion, from ν^* = 640 Hz for the parent material to ν^* = 1650 Hz and ν^* = 900 Hz for Ni- and Fe-doped materials, respectively. The ability to tune the properties of perovskites via doping, coupled with their inherent redox stability, make this class of materials an exciting possible alternative to the state-of-the-art Ni/yttria-stabilised zirconia (YSZ) cermet.

B0702

Enhanced Performances of Structured Oxygen Electrodes for High Temperature Steam Electrolysis

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Abstract

High temperature steam electrolysis is one of the most promising ways for clean hydrogen mass production. To make this technology economically suitable, each component of the system has to be optimized to reach high energetic efficiency, especially the single solid oxide electrolysis cell. Improving the oxygen electrode performances is of main interest as this electrode contributes to a large extent to the cell polarization resistance.
The present study is focused on alternative structured oxygen electrodes. The $Ln_2NiO_{4+\delta}$ (Ln = La or Pr) rare-earth nickelate oxides (with K_2NiF_4-type structure) were selected as oxygen electrode material with respect to their aptitude to accommodate oxygen overstoichiometry, leading to a mixed electronic and ionic conductivity. A thin ceria-based interfacial layer was added in between the electrode and the zirconia-based dense electrolyte to improve mechanical and electrochemical properties and to limit the chemical reactivity with this electrolyte. The selected interfacial materials were yttria-doped ceria $Ce_{0.8}Y_{0.2}O_{2-\delta}$ (YDC) and gadolinia-doped ceria $Ce_{0.8}Gd_{0.2}O_{2-\delta}$ (GDC). These structured electrodes were screen-printed, then characterized by electrochemical impedance spectroscopy measurements performed on symmetrical electrolyte-supported cells, under zero *dc* conditions and anodic polarization. Low polarization resistance R_P and improved anodic overpotential η_A *vs.* current density curves were obtained for the $Pr_2NiO_{4+\delta}$ / YDC structured electrode: R_P is decreased down to 0.06 Ω.cm² at 800°C, under air and zero *dc* conditions. The oxygen reaction limiting step was determined by varying the oxygen partial pressure $P(O_2)$ in the range 5.10^{-3} - 1 atm. At 800°C, for the $Pr_2NiO_{4+\delta}$ / YDC electrode, the molecular oxygen absorption / desorption has been identified to be the rate determining step. These results are discussed in terms of oxygen evolution processes in the temperature range 600°C - 800°C.
Then, complete hydrogen electrode-supported cells including the $Pr_2NiO_{4+\delta}$ / YDC structured oxygen electrode were characterized in terms of electrochemical performances. At 800°C, when the inlet gas composition is 90% H_2O - 10% H_2 at the hydrogen electrode, air being swept at the oxygen electrode, the current density determined at 1.3 V reaches -1 $A.cm^{-2}$, the corresponding steam to hydrogen conversion rate being 64 %. These results are compared to those obtained with a reference cell including the oxygen deficient perovskite $La_{0.6}Sr_{0.4}Fe_{0.8}Co_{0.2}O_{3-\delta}$ as oxygen electrode.

B0703

Electrochemical Characterisation of High Temperature Solid Oxide Electrolysis Cell Based on Scandia Stabilized Zirconia with Enhanced Electrode Performance

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Abstract

The present paper is focused on electrodes development for solid oxide electrolysis cell based on scandia doped zirconia (210µm) electrolyte with improved performance compared to the common cells mainly based on perovskite as cathode and Ni/GDC or Ni/YSZ as anode. The influence of different operating conditions (temperature, current density, oxidant or fuel composition) on electrochemical performance is investigated. In electrolysis mode at typical operation temperature of 850°C and current density of -300mA/cm^2 the operating voltage of 1,01V is measured. The changes in polarization resistance and difference in operation between SOFC and SOEC mode is discussed based on analysis of impedance spectra of tested cells. The degradation behavior of SOEC cell is studied in detail under current density of -300mA/cm^2 and 800°C during more than 1000h. Microstructure observations at the interfaces in both electrodes are carried out after long-term tests to understand the reasons for degradation. The technological aspects of cell production are discussed.

B0704

Durability studies of Solid Oxide Electrolysis Cells (SOEC)

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Abstract

For economical and ecological reasons, hydrogen is considered as a promising energetic vector for future. High temperature steam electrolysis (HTSE) is one of the most promising processes to produce massive hydrogen with low or no CO_2 emissions. However some technological challenges have to be overcome to improve the performance and the durability of such devices to reduce production costs and to minimize maintenance costs. For that purpose, cells materials have to be long-term stable (minimum 25 000h). A great deal of effort has already been done on long term stability of SOFC, but a lot remains to be done on long term stability of Solid Oxide Electrolysis Cells (SOEC).
Several parameters can affect the cell durability itself, which are the temperature, the current density, the voltage and the steam conversion (SC) ratio in particular. The present study focuses on the description of the single cell degradation phenomena as functions of time and condition parameters. The effect of the SC on the degradation behavior of an H_2-electrode supported cell has been investigated, with the help of i-V curves and EIS (Electrochemical Impedance Spectroscopy) measurements performed before and after operation in the selected conditions. Several SC have been considered, from 17% to 83% at the same current density (-0.5 A/cm²). It shows that higher is the SC, higher is the voltage degradation. According to characterizations performed at the operating point, the voltage degradation rate is three times higher at high SC (83%) than at low SC (17%). This ASR increase seems to be mainly due to polarisation resistance degradation. The effect of the SC ratio does not seem irreversible, since a cell previously submitted to steps at high SC presents a degradation similar to a fresh cell tested in the same conditions.
Similarly the effect of the current density has been studied. The higher is the current density, the higher is the degradation rate, with again no irreversible effect.

B0705

Influence of steam supply homogeneity on electrochemical durability of SOEC

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Abstract

High Temperature Steam Electrolysis (HTSE) is a promising technology for producing an alternative future fuel: hydrogen. This process can be done using Solid Oxide Electrolysis Cells (SOEC) and can be described as the reversely operated Solid Oxide Fuel Cells (SOFC) mode. Long term stability of these SOECs remains a critical issue. This work is focused on relatively long term-cell testing in HTSE mode to identify the degradation mechanisms detrimental for the SOEC durability.

In this aim, the electrochemical behavior of commercial electrolyte supported SOEC has been studied at 850°C for 90/10 H_2O/H_2. Several specific experimental montages have been developed in order to homogenize the steam supplying method over the hydrogen electrode. These sets-up will be first described. Then, durability tests will be presented. During these durability tests, the influence of the homogeneity of the steam supply at the hydrogen electrode has been studied as well as the influence of the operating voltage. Two cell voltages have been used: 1.3 Volt and 1.1 Volt.

The first degradation mechanism observed was oxygen electrode delamination for all the different operating conditions. Moreover, the delamination is more important for higher operating voltage (1.3V) for which oxygen production rate is higher. Because of this limitation coming from the LSM/YSZ oxygen electrode, no influence of steam distribution homogeneity was observed during these first durability tests.

In order to prevent the SOEC from delamination and to observe the eventual positive effect of gas supplying method, the modification of the oxygen electrode material composition is necessary. Moreover, impedance analyses carried out during this work enabled a better understanding of impedance diagrams of studied electrolyte supported cell. High frequencies contribution of impedance diagrams can be associated to oxygen electrode response and low frequencies contribution to hydrogen electrode.

B0706

High Temperature Electrolysis at EIFER

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Abstract

The European Institute for Energy Research is working on the application of the solid oxide cell technology for high temperature electrolysis with the aim to produce hydrogen and syngas. Since 2004, numerous tests of single cells and stacks with 5 to 25 cells have been conducted. Test durations were rather long, ranging from 1000 to 9000 hours, with current densities between 0.4 and 1 A/cm^2. A summary of the experimental results is presented with a focus on the observation of cell and stack degradation. Long term operation of cells with 45 cm^2 active area under a high current density of 1 A/cm^2 indicates an extrapolated cell lifetime of at least 20 000 h. Cell integration into short stacks shows additional constraints such as non-homogeneous cell behaviour, electrical contacting resistances of the cell interconnects which are more critical under operation at high current density, and increased degradation rates.
Techno-economical analysis have been realised in parallel to establish the hydrogen production cost by high temperature electrolysis as function of the electrolyser environment (availability of an external heat source, electricity source, hydrogen compression stages...). Finally, the hydrogen production costs using high temperature electrolysis are discussed and the high temperature electrolysis is positioned on the roadmap of development and deployment of the electrolysis technologies for hydrogen and syngas production.

B0707

Study of the electrochemical behavior of an electrode-supported cell for the electrolysis of water vapor at high temperature

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Abstract

High temperature electrolysis (HTE) is a quite recent topic where studies are usually focusing on performance measurements and degradation observations. However, only few papers report a systematic analysis on reaction mechanisms, and even fewer on degradation mechanisms, using an electrochemical tool such as electrochemical impedance spectroscopy (EIS) [1-6]. In this study, we have combined EIS to chronopotentiometry in order to characterize the electrochemical performance and behavior of a commercial cathode-supported cell. This cell is constituted by Ni-YSZ cermet as hydrogen electrode, 8%-YSZ as electrolyte and LSCF ($La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$) as oxygen electrode. The analysis of different parameters such as current density, temperature, P_{H2O}/P_{H2} ratio and cathode gas flow rate showed that impedance diagrams can be deconvoluted into 3 or 4 arcs (each one characterized by a capacitance and a relaxation frequency). A capacitance and a relaxation frequency were assigned to each frequency range, which allowed to ascribe them to a specific phenomenon. Thus, for this cell, the analysis leads to the following identification: the high frequency arc is related to charge transfer at the electrode/electrolyte interface, while the low frequency arc is attributed to gas diffusion at the hydrogen electrode [4, 5]. Further analyses are required to conclude for the middle frequency arc. This work constitutes an *in situ* diagnosis by EIS of solid oxide electrolyzer cell degradation.

B0708

Compilation of CFD Models of Various Solid Oxide Electrolyzers Analyzed at the Idaho National Laboratory

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Abstract

Various three dimensional computational fluid dynamics (CFD) models of solid oxide electrolyzers have been created and analyzed at the Idaho National Laboratory since the inception of the Nuclear Hydrogen Initiative in 2004. Three models presented herein include: a 60 cell planar cross flow with inlet and outlet plenums, a 10 cell integrated planar cross flow, and an internally manifolded five cell planar cross flow.

Mass, momentum, energy, and species conservation and transport are provided via the core features of the commercial CFD code FLUENT. A solid-oxide fuel cell (SOFC) module adds the electrochemical reactions and loss mechanisms and computation of the electric field throughout the cell. The FLUENT SOFC user-defined subroutine was modified for this work to allow for operation in the SOEC mode. Model results provide detailed profiles of temperature, Nernst potential, operating potential, activation over-potential, anode-side gas composition, cathode-side gas composition, current density and hydrogen production over a range of stack operating conditions. Predicted mean outlet hydrogen and steam concentrations vary linearly with current density, as expected. Contour plots of local electrolyte temperature, current density, and Nernst potential indicated the effects of heat transfer, endothermic reaction, Ohmic heating, and change in local gas composition.

Results are discussed for using these models in the electrolysis mode. Discussion of thermal neutral voltage, enthalpy of reaction, hydrogen production is reported herein. Contour plots and discussion show areas of likely cell degradation, flow distribution in inlet plenum, and flow distribution across and along the flow channels of the current collectors

B0709

Outcome of the Relhy project: Towards Performance and Durability of Solid Oxide Electrolyser Stacks

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Abstract

The aim of the RelHy project (FP7 2008-2011) was to take advantage of current knowledge in SOFC field to produce Solid Oxide Electrolyser stacks, reaching satisfactory compromise between performance (~-1 A cm^{-2} with a voltage across each single repeating unit in the stack lower than 1.5V) and durability (voltage degradation close to ~1% per 1000 h), with cost effective materials.

Several challenges appeared during the project, such as the reproducibility between testing partners or the control of all testing parameters for the stacks from 1, 5 to 25 cells. Indeed, for each size, steam supply and temperature management require fine tuning as confirmed by modeling approaches.

At the end of the project:
- Test setup for better reproducibility in electrolyser mode and testing conditions for higher durability have been identified,
- The best compromise for high performance and durable cells, based on current improved materials, has been proposed,
- SRUs and stacks have been adapted to electrolyser conditions: upon testing good tightness has been maintained during more than 4000 h, high initial performances and satisfactory homogeneity between cells were obtained, degradation rate was decreased with protective + contact coating and remained limited even at high current density, some conditions were even found with no degradation.
- Outstanding results have emerged from RelHy at all scales from single cells to SRUs and short stacks. Degradation rates below 5% per 1000h at high current densities have been obtained during long duration experiments (> 4000h).

Based on obtained performance and durability results, provisional production cost of hydrogen has been proposed and conditions for high temperature electrolyser competitiveness could be derived.
Finally, the remaining technical barriers of (HTE) towards large scales demonstration and the market entry possibilities have been identified.

B0711

Nanopowders for reversible oxygen electrodes in SOFC and SOEC

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Abstract

This paper aims to obtain, characterize and test three different nanopowders used as reversible oxygen electrodes in SOFC and SOEC: Lanthanum Strontium Manganate (LSM), Lanthanum Strontium Cobaltite Ferrite (LSCF) and Neodymium Nickelate (NdNi). The nanopowders were obtained at 900°C via a new modified sol gel method, using two cheap and environmentally friendly organic precursors, namely sucrose and pectin. The electrical conductivity at elevated temperatures were investigated for samples sintered from 900 – 1300°C, to ensure proper current collection without use of precious metals. The best results were obtained for $La_{0.7}Sr_{0.3}MnO_3$ (LSM30) sintered at 1300°C. The LSM electrodes were prepared by first spraying a thin layer of LSM/YSZ mixture followed by a screen-printed layer of LSM30 before sintering. For the LSCF electrode, a barrier layer of Gadolinium doped Ceria (GDC) were sprayed, with the LSCF electrode screen printed on top. Each material was sintered at different temperatures and tested from 700 to 1000°C followed by one week under constant current flow at 900°C. Characterization by XRD and SEM will also be presented and compared with the literature data.

B0712

Co-Electrolysis of Steam and Carbon Dioxide in Solid Oxide Electrolysis Cell with Ni-Based Cermet Electrode: Performance and Characterization

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Abstract

The rapid depletion of fossil fuels along with increasing pollution are of increasing concern worldwide. This is the reason for high interest in alternative and renewable energy sources in recent years. One promising route towards green energy is the synthesis of different hydrocarbon fuels from precursor syngas mixtures of $CO+H_2$, produced via sustainable methods. The Solid Oxide Electrolysis Cell (SOEC) allows syngas generation by the co-electrolysis of steam and carbon dioxide (CO_2). In this case CO_2 could be trapped from the air thereby minimizing long–term harmful effect on the environment, or it could be captured from industrial or power generation processes. However, the effects of characteristics such as gas composition, impurities, microstructure, cell design and operating conditions on SOEC performance are not fully described as yet. This motivates the present work to establish an improved understanding of the fundamental phenomena underpinning SOEC operation for steam and CO_2 co-electrolysis. Our work reported here focuses on the performance of Ni-YSZ cathodes for the electrolysis of humidified carbon dioxide/carbon monoxide mixtures. Electrode performance is assessed using three electrode measurements; initial results from experimental studies are reported.

B0713

Detailed Study of an Anode Supported Cell in Electrolyzer Mode under Thermo-Neutral Operation

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Abstract

The stability of anode-supported cells (ASC) made of a Ni/YSZ substrate and anode layer, YSZ-electrolyte, a screen printed CGO interlayer and a mixed conducting LSCF cathode, developed at Forschungszentrum Jülich was investigated under constant electrolyzer (Cell A) and cyclic (Cell B) operation modes. The cells were operated at the thermo-neutral current density of 1.5A/cm² at 800°C in a 50:50 pH_2O:pH_2 fuel electrode gas composition and air supplied to the oxygen electrode for the investigated cells and setup. Electrochemical characterization was done every 100h in both cases through Electrochemical Impedance Spectroscopy (EIS) at Open Circuit Voltage (OCV) as well as under load. Current voltage characteristics were also recorded during characterization phases.
While Cell B under cyclic operation was still perfectly operational at 1060h, Cell A broke down after 530h of operation. An extreme increase in ohmic resistance R0 of around ~40% as well as ~64% in Ni/YSZ-electrode electrochemistry (R2A+R3A) resistance (compared to 18% and 22% for Cell B) were identified to be the main source of the breakdown of Cell A.
This acute degradation was attributed to break down of ionic conductivity of the YSZ of the fuel electrode as well as of the electrolyte. For the first time in SOEC development and operation (at high current densities) we propose as mechanism responsible for the observed breakdown, a theory based on earlier work by Sonn et al. [1] and recently verified by Butz et al. in [2] for SOFC operation under reducing conditions :
During annealing of the Ni/YSZ-YSZ under oxidizing atmosphere at high temperatures (T > 1400°C), Ni^{2+} diffuses into the YSZ matrix. At high electrolyzer current densities, the Ni^{2+} cations are reduced to Ni. This leads to increased lattice parameters there-by enhancing mobilities of Y and Zr cations. As a consequence precipitation of tetragonal YSZ phase is increased that has a very much lower O^{2-} ionic conductivity than the cubic phase.

B0714

Development of a solid oxide electrolysis test stand

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Abstract

In this paper, steam electrolysis has been performed using microtubular Solid Oxide Electrolysis Cells (SOEC). These SOEC were formulated from standard materials, in a Ni/YSZ –YSZ – LSM arrangement. The tubes produced had an internal diameter of 2.3mm and a length of 55mm.
Hydrogen was humidified using a bubbler humidifier at a set temperature. The humidified gas was then fed into a bespoke test rig. Temperature of humidification, hydrogen flow rate and response to current cycling were investigated.
A current density of -430mA cm^{-2} was observed at 1.3V, in a furnace at 850°C and with a humidifier temperature of 60oC, and a hydrogen flow rate of 50ml min^{-1}. The SOEC was also cycled between fuel cell and electrolysis modes of operation. It was found that the cell voltage responded within 0.05s to a 400mA change in current from either electrolysis to fuel cell operation or vice versa.

B0715

CFD simulation of a reversible solid oxide microtubular cell

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Abstract

In this work, the authors introduce a comprehensive model, and the corresponding 3D numerical tool, for the simulation of reversible micro-tubular solid oxide fuel cells. They are based on a previous in-house model for SOFC [1], to which some new features have been added to extend their applicability to SOEC. The model considers the following physical phenomena: (i) fluid flow through channels and porous media; (ii) multicomponent mass transfer within channels and electrodes; (iii) heat transfer due to conduction, convection and radiation; (iv) charge motion; and (v) electrochemical reaction. The numerical algorithm to solve this mathematical model is implemented in OpenFOAM, an open source CFD toolbox based on the finite-volume method.
The model accurately describes the characteristic curve (I-V) of the performance of a reversible solid oxide fuel cell, in both SOEC and SOFC modes, as shown in the Figure 1, where experimental data [2] (lines) is plotted versus the numerical results (dots).

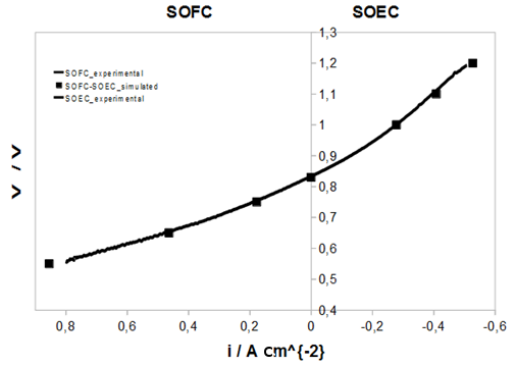

Figure 1: I-V curves, numerical versus experimental data [2].

The model is used to determine the electrochemical model parameters and to study the physics that take place in both modes of operation. The role of the physical phenomena involved in the performance of a solid-oxide device depending on the operation mode (fuel cell or electrolyser) is discussed, aiming at providing a basis for the cell optimization.

B0901

Nanostructured Electrodes forLow-Temperature Solid Oxide Fuel Cells

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Abstract

Solid oxide fuel cells (SOFCs) are attractive for clean and efficient conversion of fuels into electricity. Decreasing the operating temperature from the current 700-800°C down to 500-600°C will reduce materials and system costs, allow the use of inexpensive alloy interconnects, simply the gas sealing challenge and enhance the fuel cell durability. The inevitable decrease in power densities, due to drastically increased electrolyte resistances and electrode polarizations at low temperatures, makes it mandatory to identify effective alternatives to the state-of-the-art yttria-stabilized zirconia electrolyte and micron-scale electrode structure.
Strontium- and magnesium-doped lanthanum gallate (*LSGM*) emerges as a promising electrolyte for low-temperature SOFCs due to its high oxide ionic conductivity (*e.g.*, 0.015 S/cm at 600°C), negligible electronic conductivity as well as chemical stability over a wide oxygen partial pressure range. Nevertheless, poor chemical compatibilities between LSGM and commonly used electrode materials at high temperatures make it difficult to obtain fuel cells with thin LSGM electrolytes that are required to deliver high power densities at low temperatures. Here we report a novel approach for fabricating low-temperature SOFCs featuring 15-μm-thick LSGM electrolytes with nanostructured electrodes. The thin LSGM electrolyte is sandwiched between two porous LSGM layers that are respectively impregnated with NiO and $Sm_{0.5}Sr_{0.5}CoO_3$ after the high temperature firing step, thereby avoiding the deleterious reactions between LSGM and the active electrode components. Single SOFCs operated on humidified hydrogen fuel and air oxidant yield maximum power densities of > 1.0 Wcm^{-2} at 600°C.

B0902

Protonic ceramic fuel cells based on reactive-sintered $BaCe_{0.2}Zr_{0.7}Y_{0.1}O_{3-\delta}$ electrolytes

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Abstract

Protonic ceramic fuel cells, membrane reactors, and related intermediate-temperature electrochemical devices require thin, dense protonic ceramic membranes supported by porous substrates. Here we describe tubular anode-supported fuel cells and membrane reactors consisting of the acceptor-doped protonic ceramic $BaCe_{0.2}Zr_{0.7}Y_{0.1}O_{3-\delta}$ (BCZY27), co-fired with a cermet of 65 wt-% NiO / 35 wt-% BCZY through solid-state reactive sintering.

Charge transport across the BCZY27 membrane is complex, as the mobilities of the numerous charge carriers (protons, oxygen vacancies, holes, electrons) are unknown, coupled, and highly dependent on gas composition and temperature. Counter-diffusion of charge carriers leads to measured open-circuit voltages that are below the theoretical Nernst potential, and a small but non-zero internal shunt across the membrane is established. In this work, insight into the magnitude of the internal shunt and the mobilities of the multiple charge carriers is acquired through measurements of the open-circuit voltage of a BCZY27 membrane over a wide range of steam and hydrogen partial pressures and operating temperatures.

These measurements are acquired from a tubular, anode-supported BCZY27-based fuel cell fabricated by CoorsTek, Inc and the Colorado School of Mines. The dense BCZY27 membrane is approximately 25 μm thick, and spray coated onto a 10-mm-diameter, 1-mm-thick cermet anode support. The supports are fabricated by extrusion, and can reach up to 40 cm in length. After high-temperature co-sintering of the anode-electrolyte assembly, a $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ (BSCF) cathode is applied. The cell is sealed within a “tube-in-shell” test stand in which the gas compositions of both the fuel and oxidizer streams can be well controlled.

A series of experiments are performed in which cell open-circuit voltage is continuously measured over a broad range of anode-gas compositions and furnace temperatures. The measured open-circuit voltage is found to deviate from the theoretical Nernst potential by over 200 mV at higher operating temperatures. The data set generated through this series of experiments can be valuable in development of theory on the charge-transport processes, and the mobilities of the multiple charge carriers through the BCZY27 membrane.

B0903

ITSOFC based on innovative electrolyte and electrodes materials

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Abstract

The research on solid oxide fuel cell (SOFC) is based on both the synthesis of new materials and the design process of the cell. The main advantage of SOFC is that they can work under hydrocarbon fuel at temperature higher than ≈700°C. In the current SOFC systems, the most widely used electrolyte is YSZ which is inexpensive and shows an acceptable conductivity level. But YSZ is very refractory and its major drawback is its reactivity during the sintering process with lanthanum- and strontium-based cathode materials, which leads to the formation of an insulating layer such as $SrZrO_3$ or $La_2Zr_2O_7$. Finding new electrolyte material to replace YSZ or new cathode material are some of the issues. This talk deals with the development of solid oxide cells based on a new class of electrolyte materials developed in IMN-Nantes derived from $Ba_2In_2O_5$, where indium is substituted by titanium $BaIn_{0.3}Ti_{0.7}O_{2.85}$ (BIT0.7) and new mixed ionic and electronic conductor (MIEC) cathode materials developed in ICMCB-Bordeaux, such as $Pr_2NiO_{4+\delta}$.
Complete SOFC-cells have been elaborated and tested in the framework of the French ANR public funded project INNOSOFC (2009-2012). Based on previous mentioned electrolyte and cathode materials, anode supported cells have been elaborated using different ways of shaping, tape casting, vacuum slip casting, screen-printing .
A maximum power density of about 400 $mW.cm^{-2}$ at 700 °C under wet (2.5 % H_2O) H_2 on the anode side, and air on the cathode side, has been reached and will be presented. The area specific resistance of this cell is of about 0.54 Ωcm² at 700 °C, under the same atmosphere conditions.

ACKNOWLEDGEMENT:
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B0904

New Cercer Cathodes of Electronic and Protonic Conducting Ceramic Composites for Proton Conducting Solid Oxide Fuel Cells

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Abstract

Currently investigated cathodes in proton conducting solid oxide fuel cells (PC-SOFC) are principally based on materials employed in oxygen-ion conducting SOFC cathodes. Recently, materials based on ceramic-ceramic composites (cercer) [1-4], combining a proton conducting phase and an electronic conducting phase, have shown appealing electrochemical results. This work presents the electrochemical properties of different mixed-conducting cercer composites as PC-SOFC cathodes for two different kinds of protonic electrolytes:
(1) $La_{0.8}Sr_{0.2}MnO_{3-\delta}$ – $La_{0.995}Ca_{0.005}NbO_{4-\delta}$ (LSM-LCN) cathode on LCN electrolyte.
(2) $La_{0.8}Sr_{0.2}MnO_{3-\delta}$ – $La_6WO_{12-\delta}$ (LSM-LWO) cathode on LWO electrolyte.
Different ratios of the electronic and the protonic phases have studied in the cathode preparation in order to study the influence of each one on the electrode processes. Symmetrical cell testing was accomplished by means of electrochemical impedance spectroscopy (EIS) in wet air in order to characterize the composite cathodes in the temperature range 700-900ºC. Different dilutions on both oxygen partial pressure and water content have been performed as a function of the temperature in order to characterize the processes (surface reaction and charge transport) occurring at the composite electrode under oxidizing conditions. Moreover, the role of the protonic transport has been studied by replacing protonic water by deuterated water.
The introduction of a protonic phase in the electronic (LSM) cathode allows the reduction of the polarization resistance (Rp) due to the increase of three phase boundary area along the whole thickness of the cathode. On the other hand, a high amount of protonic phase produces an increase in Rp due to the lowest total conductivity of the cathode. Balanced electrodes (50-50 vol% for LSM-LCN composites and 40-60 vol% for LSM-LWO) show the lowest Rp at any tested temperature in humidified air. Different limiting processes have been identified depending on the electrolyte material. Finally, the effect of the addition of nanodispersed catalysts on the electrode surface has been investigated.

B0905

Cathode Materials for Low Temperature Protonic Oxide Fuel Cells

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Abstract

As with solid oxide fuel cells (SOFCs) based on oxygen ion conducting electrolytes, work with protonic ceramic membrane fuel cells (PCMFCs) focuses on reducing operating temperatures. Key to achieving this temperature reduction lies in understanding the cathode processes, transport numbers of the cell components and mechanisms of proton conduction, in addition to seeking new potential materials. The cathode processes of the protonic cell are regarded to be more complex compared with cells based on oxygen ion conducting electrolytes, and there appears to be some dispute in the literature as to the exact requirements of the cathode, and if these requirements can be met with single phase materials. In a purely proton conducting electrolyte, it would appear that the optimum cathode should be a mixed proton/electron conductor. However, as the splitting of O_2 at the cathode may be a rate limiting step, there are reports of comparable performance with the more traditional mixed hole-oxide ion conductors. Heavily substituted perovskites, such as those in the $LnBaCo_2O_{5+\delta}$ series, can show protonic, oxygen ion and p-type conductivity, depending on how the acceptor is compensated. Generally, one type of conductivity dominates e.g. electronic in $GdBaCo_2O_{5+\delta}$ (GBCO). This work seeks to determine the importance of the element of protonic conductivity for the protonic cell cathode processes. Analogous to previous work done to determine oxygen surface exchange (k*) and oxygen tracer exchange (D*) coefficients in the $LnBaCo_2O_{5+\delta}$ series, using the isotope ($^{18}O/^{16}O$) exchange depth profile (IEDP) method, we present our findings from determining proton surface exchange using the same method.

B0906

Characterization of PCFC-Electrolytes Deposited by Reactive Magnetron Sputtering and comparison with their pellet samples

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Abstract

$SrZr_{0.84}Y_{0.16}O_{3-\alpha}$ (SZY16), $BaZr_{0.84}Y_{0.16}O_{3-\alpha}$ (BZY16), $BaCe_{0.8}Zr_{0.1}Y_{0.1}O_{3-\alpha}$ (BCZY10) and $BaCe_{0.90}Y_{0.10}O_{3-\alpha}$ (BCY10) coatings are suitably deposited by reactive magnetron sputtering from metallic targets in the presence of argon-oxygen gas mixtures and the corresponding bulk samples are prepared by solid state reaction. In order to obtain dense BZY16 and BCZY10 samples, 1 wt.% ZnO was added before sintering process.
As deposited films are amorphous and crystallise under convenient crystal structure at different temperatures (e.g. SZY16 ≈ 623 K; BZY16 ≈ 423 K; BCY10 ≈ 873 K and BCZY10 ≈ 873 K). SZY16 and BZY16 coatings are stable in air with respect to carbonation and hydration. BZY16 coatings require an in situ crystallization in order to avoid further cracking of the coating due to the tensile stress generation associated with the crystallization phenomenon, so they are deposited directly on hot substrate ($T_{substrate}$ ≈ 523 K). BCZY10 amorphous coatings present a good chemical stability against carbonation in air up to 573 K but the coatings decompose in $BaCO_3$ and CeO_2 mixture after annealing treatment at around 873 K for 2 hours in air, in spite of the targeted double substituted $BaCeO_3$ perovskite structure. Nevertheless, the crystallization in the convenient perovskite structure was obtained after annealing treatment under vacuum to prevent the carbonation of the coating. BCY10 requires in situ crystallisation ($T_{substrate}$ ≈ 873 K) to obtain $BaCeO_3$ structure while avoiding the carbonation of the film. All of the bulk samples present pure perovskite structure with a relative density higher than ~75% and no trace of ZnO and $BaCO_3$ was detected. The electrical properties of the films and pellets are investigated by AC impedance spectroscopy in air. Conductivities of crystallised coatings are close but they are lower than those of bulk samples with the same composition.

B0907

Synthesis and electrochemical characterization of T* based cuprate as a cathode material for solid oxide fuel cell

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Abstract

The synthesis and electrochemical characterization of T* based La0.9Gd0.9Sr0.2CuO4-δ (LGSCu) has been carried out in order to use as a cathode material for solid oxide fuel cell application. XRD studies demonstrate a phase pure material that matches with the JCPDF (# 79-1861), belong to space group of P4/nmmz. The electrical conductivity value decreases from 22 Scm-1 at room temperature to 11 Scm-1 at 880 o C. with a semiconductor to metallic transition behavior observed at 550 oC at a maximum conductivity of 28 Scm-1. A decrease in conductivity, decreasing the partial pressure of oxygen implying the above material is p-type conductor and also stable at this temperature in Argon atmosphere. The Coefficient of thermal expansion value measured from Dilatometry is 12.6 * 10 -6 K-1 which matches with Gd doped CeO2 (CGO). Symmetrical cell testing results shows that the area specific resistance is 0.35 ohm.cm2 at 800 oC when the cathode material is screen printed on CGO electrolyte and sintered at 900 oC for 1 hr.

B0908

The Effect of Transition Metal Dopants on the Sintering and Electrical Properties of Cerium Gadolinium Oxide

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Abstract

Cerium gadolinium oxide ($Ce_{0.9}Gd_{0.1}O_{1.95}$, CGO) is a promising candidate for use as an electrolyte material in intermediate temperature solid oxide fuel cells. Within this operating temperature range, CGO has shown some of the highest reported ionic conductivity values. One disadvantage of using CGO relates to its relatively poor densification behavior at lower sintering temperatures. The introduction of certain transition metal oxide (TMO) sintering aids has previously been reported to improve the densification behavior of CGO without having a deleterious effect on the conductivity. In particular, low concentrations of cobalt oxide (1-2 cat%) have been shown to be effective. The recent impetus to reduce the operating temperature to 500-700°C for small scale power generation has enabled the use of cheaper stainless steel interconnects, which share a similar thermal expansion coefficient to CGO and metal-supported electrolyte cells. It is however likely that the use of stainless steel supports and interconnects will lead to elements from the steel (in particular Cr) entering the electrolyte during manufacture, which will effectively lead to multiple doping of the electrolyte.

In the current work the effects of low level TMO doping (Co and Cr) on the densification and electrical properties of CGO were analyzed singularly and in combination using dilatometry and AC impedance spectroscopy. The experiments show that Co promotes densification whilst Cr has a strong retarding effect. When both Co and Cr are present the Co nullifies the inhibiting effect of Cr. Neither of the TMOs has a detectable influence on the lattice ionic conductivity; although Co was shown to increase the grain boundary conductivity at low temperatures whilst Cr was shown to reduce it. In the case of Cr, the reduction is particularly severe and is apparent even at low concentrations.

B0909

Enhancement of Ionic Conductivity and Flexural Strength of Scandia Stabilized Zirconia by Alumina Addition

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Abstract

Electrolytes with high ionic conductivity and flexural strength are required for electrolyte-supported solid oxide fuel cells (SOFCs). Adding alumina have effect on both conductivity and flexural strength.In this paper, 10 mol% scandia and 1 mol% CeO2-stabilized zirconia (10Sc1CeSZ) electrolytes with 0 – 5 wt% alumina are prepared and characterized. The bulk resistance is always increased by the addition of alumina. The grainboundary resistance is significantly reduced when adding small amounts (<2 wt%) of alumina with a little change in the bulk resistance. The lowest total resistance is achieved by adding 0.5 wt% measured by electrochamical impedance spectroscopy. The flexural strength of all samples is improved with added alumina. Only by adding 0.25 wt% alumina, the flexural strength is enhanced from 397 MPa to 500 MPa. The results surggest that the optimum adding amount should be within the limit of 1wt%, with the benefits of enhancement in both ionic conductivity and flexural strength.

B0910

Development of proton conducting solid oxide fuel cells produced by plasma spraying

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Abstract

Proton conducting solid oxide fuel cells enables cell operation at intermediate temperatures between 550 to 650°C and as the water formation occurs in the cathode, the dilution of fuel can be avoided. Ytrria-doped barium cerates (BCY) are the commonly used electrolyte materials. These refractory materials need high sintering temperatures of above 1550°C to achieve a full dense electrolyte. The BCY undergoes chemical decomposition during dwell at sintering temperature and also reacts with the NiO of the anode material. The NiO diffuses into the BCY electrolyte and segregates at the grain boundaries leading to electronic conductivity in the electrolyte. To avoid these obstacles, plasma sprayed IT-PCFC cells were developed. In plasma spraying, powder particles are molten and impacted on a substrate where they solidify and consolidate to form coating. Since the heating and cooling rates are very high (melting and solidification occurs in micro-seconds), diffusion dependent chemical interactions or decomposition can be avoided.

BCY15 material from Saint Gobain was sprayed using vacuum or atmospheric plasma spraying. Employing the design of experiments, the correlation between the process parameters and key characteristics of the deposit were established. Under low pressure, considerable percentage of Ba evaporated from the material and condensates in the deposit. After getting in contact with air, barium carbonate formed leading to micro to macro cracking of the coatings. The cell produced with VPS electrolyte also demonstrated low performance. In atmospheric spraying the vaporization could be suppressed depending on the enthalpy of the plasma. With lower enthalpy plasma, BCY layer with 90% density can be produced. The anode was also developed, containing 50 vol.% NiO and 50 vol.% BCY. The cells produced in this manner resulted in max. power of 90 at 650°C with hydrogen and air.

Work is in progress to improve further the plasma sprayed anode and electrolyte layers for PCFC.

B0911

Development of Solid Oxide Fuel Cells based on $BaIn_{0.3}Ti_{0.7}O_{2.85}$ (BIT07) electrolyte

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Abstract

Until now, major hurdles to the industrial deployment of the SOFC technology remain reliability and costs. In this context, a decrease of the operating temperature is considered as a relevant approach to slow down thermally-activated degradation processes of components such as corrosion of metallic interconnect and so to extend the lifetime of SOFC. Beside, innovative materials with higher performances and electrocatalytic properties at intermediate temperatures (below 750°C) are needed. As a potentially alternative electrolyte material, the perovskite $BaIn_{0.3}Ti_{0.7}O_{2.85}$ (labelled BIT07) shows a targeted ionic conductivity of 10^{-2} S cm^{-1} at 700°C and is stable under both oxidizing and reducing atmospheres. Cathode materials to be associated with BIT07 could be the nickelates of lanthanide $Ln_{2-x}NiO_{4+\delta}$ (Ln = La, Nd, Pr) owning reasonable catalytic properties and mixed ionic/electronic conductivity (for example, for $Pr_2NiO_{4+\delta}$, σ_{tot} = 100 S cm^{-1}, σ_{ionic} = 2.6×10^{-2} S cm^{-1}, D* = 5×10^{-8} cm^2 s^{-1} and k = 1.5×10^{-6} cm s^{-1} at 700°C).

The purpose of the present work is to investigate the potential of these alternative materials by coupling them in an anode-supported SOFC architecture which can operate at intermediate temperatures.

Innovative IT-SOFC cells (size 40x40 mm^2) have been successfully produced by industrially scalable wet routes: tape casting, slip casting and screen-printing. These cells have been studied by electrochemical measurements. First test of performance showed 43 mW cm^{-2} at 0.7 V and 800°C for a cell BIT07/NiO | BIT07 | $Pr_{1.97}NiO_{4+\delta}$. This type of IT-SOFC cell has been successfully operated beyond 150 hours with a reasonable degradation of 6 % / kh. Technological hurdles (microstructure, interfaces adherence…) have been identified and potential solutions are proposed for improving the whole performance and reliability of the system.

B0912

A Direct Methane SOFC Using Doped Ni-ScSZ Anodes For Intermediate Temperature Operation

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Abstract

Solid Oxide Fuel Cell (SOFC) systems operate at temperatures 500 – 950°C and have garnered interest in recent years due to their higher conversion efficiencies when compared to heat engines, variable fuel capability, low noise operation and cell design flexibility [1]. While these advantages make SOFCs one of the most sought after technologies, the technical challenges associated with high temperature operation and the issues with the utilization of hydrocarbon fuels currently create economic barriers for widespread implementation. Developing SOFC systems that operate directly on hydrocarbon fuels allows immediate use of fossil fuels, eliminates the need for separate fuel reformers and purification systems and allows by-product heat to be recycled back into the cell stack or used in a cogeneration heat and power application. Direct hydrocarbon fuel utilization coupled with low temperature operation may create new operating difficulties but at the same time system stability and materials degradation may be improved so that a decrease in temperature promises major cost benefits and promotes an ever increasing interest in SOFC commercialization, solidifying their position in the new energy economy [2, 3].
Conventional nickel-yttria stabilised zirconia (Ni-YSZ) is the most developed and most commonly used anode because of its low cost and exceptional performance in H_2 rich environments but under hydrocarbon operation, Ni-YSZ can deteriorate significantly due to low sulphur tolerances and carbon poisoning [4-6]. Literature states that Ni-based cermets containing metals and metal alloys demonstrate high catalytic activity for hydrocarbon oxidation and are slower for carbon catalysis than Ni alone [7-12]. Power densities of .33W/cm^2 (800°C) have been obtained for single cells using Cu-Ni-CeO/YSZ anodes (YSZ electrolytes) and .75W/cm^2 (600°C) for single cells using Ru-Ni/GDC anodes (GDC electrolytes) both operating on direct methane [9-11]. While these studies show proof of concept, extensive research is necessary to find cheaper, better performing catalysts for nickel-zirconia anodes that exhibit performance stability on hydrocarbon fuels over extended lifetimes and at lower temperatures.

The aim of this work is to demonstrate direct methane SOFC operation by developing new Ni based ZrO_2 anode formulations that suppress carbon formation and are stable against sulphur impurities without sacrificing cell performance. Alternative electrolyte systems will be examined to measure their impact on cell performance and intermediate temperature operation.

B0913

Challenges of carbonate/oxide composite electrolytes for Solid Oxide Fuel Cells

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Abstract

New highly conductive electrolytes for intermediate-temperature solid oxide fuel cells (T<700°C) constitute a challenging field. Among them, composite materials based on mixtures of alkali carbonates and ceria-based compounds have attracted a growing interest in the last decade [1-5]. According to some authors, these materials, with enhanced ionic conductivity, are supposed to conduct both oxygen ion and protons. Oxide ions ensure the conductivity in the oxide phase and protons conduction would be predominant in the carbonate phase. Moreover, the carbonate eutectic being molten at intermediate temperature (>500°C) would create an interfacial conduction pathway, which may also involve protons. The hypothesis of significant proton conduction is far from being proven and the real mechanism paths are still controversial. Different approaches can be found in the recent literature, but they all outline a complex ionic transport at the interface between oxides and carbonates. A deeper view is required, in particular, on the understanding of the melt chemistry of carbonates with possible dissolved species as water and hydroxides. We will report in the paper new and original results concerning the electrochemical behaviour of composite materials in reducing atmosphere. Furthermore, we will present perspectives for modified carbonate phase in such potential electrolyte.

B0914

Optimisation of anode/electrolyte assemblies for SOFC based on BaIn0.3Ti0.7O2.85 (BIT07)-Ni/BIT07 using interfacial anodic layers

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Abstract

Nowadays, Solid Oxide Fuel Cells (SOFCs) operate at 500-800°C. At such temperatures, the electrolyte must exhibit a specific ionic conductivity level around 10^{-2} S.cm$^{-1,}$ and according to this criterion, $BaIn_{0.3}Ti_{0.7}O_{2.85}$ (BIT07), prepared as a thin layer in order to further limit the ohmic loss, is regarded as a potential electrolyte material [1].

The most common SOFC anodes are cermets, i.e. composites based on a ceramic material (similar the one used on the electrolyte), which will bring the ionic conductivity and a metal (nickel) which will bring both the electronic conductivity and catalytic properties towards the hydrogen oxidation. That kind of anodes presents a thermal expansion coefficient very close the electrolyte one, which should lead to a good mechanical stability. The anode microstructure must be optimised (porosity, phase distribution and particle size), with a ceramic network which enables to (i) allow the gas flow through the entire anode and (ii) assure the cell's mechanical stability. To increase the triple phase boundary (TPB), the nickel particles should be homogeneously spread throughout the ceramic matrix to form a continuous percolating network.

By using tape casting, co-sintering and serigraphy, complete cells BIT07-Ni/BIT07/LSCF have been prepared. In order to improve the contact between Ni/BIT07 and BIT07 and to facilitate oxygen ions mobility, a thin anode functional/active layer (AFL/AAL) is used. The effect of this layer on the electrochemical performance of the symmetrical cells is discussed in this communication. It is shown that the presence of AAL decreases the ASR by a factor about two (0.2 Ω.cm^2 at 700°C).

B0915

Metallic nanoparticles and proton conductivity: improving proton conductivity of $BaCe_{0.9}Y_{0.1}O_{3-\delta}$ and $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_{3-\delta}$ by Ni-doping

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Abstract

Metallic nanoparticles (Ni, Ru) catalyze the hydrogen dissociation and can consequently facilitate the incorporation of protons in ceramic oxides: $\frac{1}{2}(H_2)(g)+O_O^x \leftrightarrow (OH)_O^{\bullet}+e^{'}$ In this work we have used this approach to improve proton conductivity of both ceramic electrolyte $BaCe_{0.9}Y_{0.1}O_{3-\delta}$ (BCY) and the electrode material $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_{3-\delta}$ (LSCM). Instead of adding metallic nanoparticles as a separate phase, they were dissolved in the compounds as their oxidized form. The metal nanoparticles precipitated from compounds upon heating under reducing atmosphere [1-2]. Two families of Ni-doped compounds were studied: $BaCe_{0.9-x}Y_{0.1}Ni_xO_{3-\delta}$ ($0\le x\le 0.2$) and $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5-x}Ni_xO_{3-\delta}$ (x=0, 0.06 and 0.2). The incorporation of Ni in BCY and its subsequent partial exsolution, improves considerably total conductivity under reducing atmosphere. Below 600°C $BaCe_{0.9-x}Y_{0.1}Ni_xO_{3-\delta}$ compounds exhibit higher conductivity than BCY. Thus, at 500°C an increase of one order of magnitude was observed for $BaCe_{0.7}Y_{0.1}Ni_{0.2}O_{3-\delta}$ ($\sigma_{500°C}$= 1.7 10^{-2} S.cm^{-1}). The temperature dependence of conductivity is not linear. The curvature of the plots above 600°C suggests a protonic contribution to the total conductivity and is related to loss of protonic defects. This phenomenon is more pronounced for the compounds containing more nickel in surface (determined by XPS) which can facilitate the dissociation of hydrogen and the incorporation of protons in the structure. The electronic conductivity of Ni doped compounds was evaluated as a function of oxygen partial pressures by using Hebb–Wagner method [3-4]. The electronic contribution to the total conductivity is negligible below 600°C. $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5-x}Ni_xO_{3-\delta}$ compounds exhibit a similar behaviour. As BCY Ni-doped compounds, any compound does not present a linear dependence of conductivity with the temperature. The curvature of the plots below 400°C suggests a protonic contribution to the total conductivity. NMR results confirm that these compounds contain protons.

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B1001

Elementary Kinetics and Mass Transport in LSCF-Based Cathodes: Modeling and Experimental Validation

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Abstract

We present a combined modeling and experimental study of electrochemical oxygen reduction at mixed-conducting solid oxide fuel cell (SOFC) cathodes. Experimentally, a variety of $L_{0.6}S_{0.4}C_{0.8}F_{0.2}O_{3-\delta}/C_{0.9}G_{0.1}O_{2-\alpha}$ (LSCF/CGO) composite electrodes with different microstructures was synthesized and characterized using symmetrical cells with CGO electrolyte. Electrochemical impedance spectra were recorded at open circuit over a frequency range of 10 mHz - 100 kHz with a voltage stimulus of 10 mV. Impedance spectra typically consisted of three distinct features.
An electrochemical half-cell model based on electrochemistry and mass transport was developed and validated. The electrochemistry model is based on the (*i*) elementary kinetic description of (electro-)chemical reactions [1], (*ii*) thermodynamically consistent reaction mechanism, (*iii*) physically meaningful surface potential step and electric potentials following Fleig [2]. Two types of double layers (dl) were taken into account, that are, a surface dl formed by adsorbed negatively charged oxygen ions on the LSCF surface and positively charged sub-surface vacancies, and an interfacial dl at the contact between bulk LSCF and bulk CGO. For the mass transport model, two scales are taken into account, (*i*) porous gas-phase diffusion in the electrode using a coupled Fickian/Darcy transport mechanism, (*ii*) gas-phase transport along cathode channel above the electrode using a CSTR model.
Based on numerical impedance simulations, experimental data were successfully reproduced over all gas compositions and operating temperatures range. The three experimentally observed features of the impedance spectra were attributed to (*i*) gas diffusion in cathode channel (lower frequency part), (*ii*) electrochemical oxygen reduction on the LSCF surface and incorporation into LSCF bulk and (*iii*) charge-transfer of double negatively charged oxygen through two-phase boundary between LSCF and CGO, associated with an electrochemical double layer. Thus, the simulation allows a physically-based assignment of observed gas concentration and electrochemical impedance processes.

B1002

Three Dimensional Microstructures and Mechanical Properties of Porous $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ Cathodes

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Abstract

The three dimensional (3D) microstructures of electrodes and their interfaces with electrolytes are of crucial importance for the performance of solid oxide fuel cells (SOFCs). They not only affect the overall electrode kinetics and thus the electrochemical reaction efficiency, but also the mechanical properties of the electrodes, which greatly influence the durability of SOFCs. It is necessary to balance the trade-off between the electrochemical performance, for which higher porosities are favorable, and the ability to withstand mechanical forces, which can be improved by densification.
Currently, numerous studies can be found regarding 3D anode microstructures, but there are very few on cathodes. Moreover, no research has been conducted to establish the relationship between the detailed microstructures and the mechanical properties of cathodes.
In this work, nanoindentation is used to measure the mechanical properties (elastic moduli) of porous $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF) films. The 3D microstructural features of the LSCF films are characterized by dual-beam focused ion beam/scanning electron microscope (FIB/SEM) technique. The elastic properties of the 3D microstructures are then computed using finite element modeling (FEM). The computed elastic moduli are compared with the measured ones and found to be in good agreement.

B1003

3D Quantitative Characterization of Nickel-Yttria-stabilized Zirconia Solid Oxide Fuel Cell Anode Microstructure in Operation

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Abstract

The anode microstructural evolution is correlated to its electrochemical characteristics during a long time operation for conventional nickel-yttria-stabilized zirconia composite anode. Self made anode performance degraded with operation time in humidified hydrogen, with the increases of both ohmic and polarization losses. The anode samples after different discharging times were analyzed by 3-dimensional microstructure reconstruction based on focused ion beam-scanning electron microscopy technique. Nickel connectivity, nickel-yttria-stabilized zirconia interface area and the active three-phases-boundary length were correlated to the anode degradation. The influences of bulk gas humidity and current density were also investigated to reveal their contributions to the anode degradation.

B1004

Mechanical Characteristics of Electrolytes assessed with Resonant Ultrasound Spectroscopy

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Abstract

It is known that the thin electrolyte layer of anode supported SOFCs is under a state of high residual stress. This can affect the electrochemical performance of the device, since the stress will alter the lattice constant and thereby the conductivity. The X-ray diffraction method has shown to be successful for assessing stress states of ceramic materials; however, it requires accurate knowledge of elastic constants and furthermore for thin electrolytes the X-rays might penetrate deeper than the actual layer thickness. In the present study, a stress evaluation methodology based on resonant ultrasound spectroscopy (RUS) is proposed. A symmetric layered planar half-cell sample consisting of an anode substrate with two thin electrolyte layers on its surfaces was used for the study. The RUS measurement system set-up and resonant frequencies measurement are outlined in detail. A modal analysis, which was based on the finite element method (FEM), permitted the natural frequencies of the sample to be calculated. The selective sensitivity of the natural frequencies of some particular resonant modes to changes in stress state could be verified. In fact, comparing the resonant frequencies measured by the experiment with the natural frequencies calculated by the modal analysis, the residual stress distribution in the sample as well as the elastic modulus of the electrolyte thin-layer could be determined. Hence, it is proven that the proposed method can be a powerful tool to determine residual stress distributions as well as elastic constants of thin-layered systems.

B1005

Dynamic 3D FEM Model of mixed conducting SOFC Cathodes

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Abstract

The performance of solid oxide fuel cells (SOFC) is mainly determined by the polarization losses in the electrodes. In case of a mixed ionic-electronic conducting (MIEC) $La_{0.58}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF) cathode, the loss processes are affected by material properties, the porous microstructure and the operating conditions.
In this work we present a dynamic 3D FEM impedance model which is based on our formerly presented stationary model and allows the space and time resolved simulation of processes occurring in the cathode such as gas diffusion in the pores, oxygen exchange between the gas phase and the mixed conductor, ionic bulk diffusion and charge transfer between the MIEC-cathode / electrolyte interface as well as the ionic conduction of the electrolyte. Reconstructed microstructures gained by focus ion beam tomography as well as artificial geometries produced by a geometry generator can be used to predict the cathode performance. The developed model is validated by comparing the simulated impedance spectra with measurements of anode supported cells. By applying different operating conditions, the simulations allowed us to identify the impact of single loss contributions such as gas-diffusion to the total polarization resistance.

B1006

Detailed electrochemical characterisation of large SOFC stacks

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Abstract

As solid oxide fuel cell (SOFC) technology is moving closer to a commercial break through, lifetime limiting factors, determination of the limits of safe operation and methods to measure the “state-of-health” of operating cells and stacks are becoming of increasing interest. This requires application of advanced methods for detailed electrochemical characterisation during operation. An operating stack is subject to steep compositional gradients in the gaseous reactant streams, and significant temperature gradients across each cell and across the stack, which makes it a complex system to analyse in detail. Today one is forced to use mathematical modelling to extract information about existing gradients and cell resistances in operating stacks, as mature techniques for local probing are not available. This type of spatially resolved information is essential for model refinement and validation, and helps to further the technological stack development. Further, more detailed information obtained from operating stacks is essential for developing appropriate process monitoring and control protocols for stack and system developers.

An experimental stack with low ohmic resistance from Topsoe Fuel Cell A/S was characterised in detail using electrochemical impedance spectroscopy.
An investigation of the optimal geometrical placement of the current probes and voltage probes was carried out in order to minimise measurement errors caused by stray impedances. Unwanted stray impedances are particularly problematic at high frequencies. Stray impedances may be caused by mutual inductance and stray capacitance in the geometrical set-up and do not describe the fuel cell. Three different stack geometries were investigated by electrochemical impedance spectroscopy.

Impedance measurements were carried out at a range of ac perturbation amplitudes in order to investigate linearity of the response and the signal-to-noise ratio. Separation of the measured impedance into series and polarisation resistances was possible.

B1008

Evaluation of fuel utilization performance of intermediate-temperature-operating solid oxide fuel cell power-generation unit

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Abstract

We show the fuel utilization characteristics in an SOFC power-generation unit with an anode-supported solid oxide fuel cell in detail, as a step towards establishing stable power generation with high fuel utilization. In the experimental analysis, we used an SOFC power-generation unit containing an anode-supported planar cell, an anode seal structure, and metallic separators with radial gas flow channels. To clarify the fuel utilization characteristics, the amount of air invasion to fuel channel were estimated from water vapor partial pressure in anode exhaust gas. A small amount of fuel leakage, but as high as 14 ml/min, is shown to have a strong influence on 95% fuel utilization condition. We also demonstrate that it has little influence at 4 ml/min in the present structure. When the amount of fuel leakage is 14 ml/min, we estimated that water vapor partial pressure in the anode vicinity of the fuel outlet is estimated to be 98.9%. This is very close to the value of nickel-oxidation water partial pressure, 99.6%, derived from thermo-equilibrium calculations.

B1009

Direct Measurement of Oxygen Diffusion along YSZ/MgO(100) Interface using ^{18}O and High Resolution SIMS

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Abstract

Yttria stabilized zirconia (YSZ) is the most popular material used as an electrolyte for solid oxide fuel cells (SOFCs) because of its high ionic conductivity and chemical stability. Recent studies have reported enhanced conductivity of nano-scale YSZ of several orders of magnitude compared to that of bulk material when fabricated on well-ordered single crystalline substrates. Kosacki et al. reported the conductivity of highly textured cubic YSZ thin films deposited on MgO(100) substrates and Garcia-Barriocanal et al. investigated the conductivity of epitaxial heterostructured YSZ thin films sandwiched between 10-nm thick $SrTiO_3$(STO) layers without the YSZ surface. They have speculated that the interface between the YSZ films and the other layers would play a determining role in the outstanding conductivity properties observed by electrochemical impedance spectroscopy (EIS). However, there was no direct evidence that the diffusion of oxide ions had truly contributed to the enhanced electrical conduction along those interfaces. The objective of the present study is to measure diffusion of oxide ions along the YSZ layer textured on single crystal substrates.
In this work, we fabricated highly textured thin YSZ8 (8%Y_2O_3-doped ZrO_2) layers on MgO(100) substrates (MTI Corp.) using pulsed laser deposition (PLD). Next, a PLD Al_2O_3 was deposited on the YSZ8 films without exposure to air or other environments. The PLD Al_2O_3 layer is commonly used as an oxygen diffusion block. To ensure the oxygen incorporation block on surface, a gold layer was coated on the PLD Al_2O_3 surface. Then, we made a 100nm-deep trench of 5μm x 10μm area, exposing the lateral surface of the Au/Al_2O_3/YSZ/MgO layers by focused ion beam (FIB) milling. The samples were annealed at 210Torr of >99% $^{18}O_2$ oxygen isotope gas after pre-annealing in normal oxygen environments. Profiles of ^{18}O diffusion were collected by nanometer-scale secondary ion mass spectrometry (NanoSIMS) layer-by-layer along the direction of YSZ film thickness. The profile ^{18}O diffused parallel to the film planes was measured in several previous studies.

B1010

CO Oxidation at the SOFC Ni/YSZ Anode: Langmuir-Hinshelwood and Mars-van-Krevelen versus Eley-Rideal Reaction Pathways

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Abstract

In technical solid oxide fuel cell (SOFC) systems practically relevant fuels are reformate gases and hydrocarbons where carbon monoxide (CO) is either used directly or is formed *in situ*. The oxidation of CO can take place via heterogeneously catalyzed reactions at the triple phase boundary (TPB) of gas-phase, Ni electrode and YSZ electrolyte. In the field of heterogeneous catalysis, CO oxidation on metal and metal oxide surfaces is generally believed to occur via Langmuir-Hinshelwood (LH) and Mars-van-Krevelen (MvK) elementary reaction mechanisms, respectively. In a recent experimental and theoretical investigation of Ni, CO-CO_2|YSZ SOFC model anode systems, however, evidence for the occurrence of Eley-Rideal (ER) type heterogeneous thermal CO oxidation reaction steps on both the Ni anode material and the YSZ electrolyte was found [1]. In the present contribution, results of comprehensive quantum chemical calculations, performed in the framework of Density-Functional Theory (DFT), are presented, in which the energetics of CO adsorption and CO oxidation kinetics via the above mentioned reaction pathways over Ni and YSZ surfaces were investigated. The results allow assessing the relative importance of these three mechanisms and their influence on the overall CO oxidation kinetics over Ni, CO-CO_2|YSZ SOFC model anodes.

B1011

Electrochemical Impedance Modeling of Reformate-Fuelled Anode-Supported SOFC

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Abstract

An approach to the understanding of the gas transport properties within reformate-fueled SOCF anodes via electrochemical impedance modeling is presented. In this work, a transient FEM model is developed in COMSOL. Aim of the model is the simulation of electrochemical impedance spectra (EIS) of reformate-fuelled planar anode-supported SOFCs.
The isothermal model represents one-dimensional gas transport and reforming chemistry through the anode thickness. Porous-media transport within the electrode structure is represented by the Stefan-Maxwell model. Heterogeneous (catalytic reforming) chemistry on the Ni-surfaces is modeled with a global reaction mechanism. Charge-transfer chemistry at the electrode-electrolyte interface is modeled with a simple time-dependent rate equation.
Output of the model is a transient, space-resolved prediction of the gas composition within the anode, from which EIS spectra can be simulated. As the model is capable to coherently calculate the complex coupling of species transport phenomena and reforming kinetics, the characteristics of EIS spectra measured under reformate operation can be reproduced. After validation with experimental data, the simulation results are used to analyze the coupling of reforming chemistry and gas transport. The resulting gas transport properties within reformate-fueled SOFC anodes are explained with the model.

B1012

Advanced impedance study of LSM/8YSZ-cathodes by means of distribution of relaxation times (DRT)

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Abstract

The impedance response of a composite LSM-cathode is analyzed for a broad range of operating conditions to set up an appropriate equivalent circuit model.
The investigated double-layered cathode, developed at Forschungszentrum Jülich, is composed of a single-phase LSM ($La_{0.65}Sr_{0.3}MnO_3$) current collector and a two-phase LSM/8YSZ functional layer. Electrochemical impedance spectroscopy (EIS) measurements are preformed at different temperatures in a range of 700°C to 900°C and a variation of oxygen/nitrogen composition in a range of 0.85 to 0.02 atm (N_2/O_2).
High resolution EIS analyses are carried out with the help of the distribution of relaxation time (DRT). By means of the DRT, for the first time, four different loss mechanisms are clearly distinguishable in the double-layered cathode. Three polarization losses are systematically dependent on oxygen partial pressure, whereas only one of these shows no dependency on temperature. The third and high frequency loss mechanism is thermally activated and shows a minor dependency on oxygen partial pressure.

B1013

Thermal diffusivities of $La_{0.6}Sr_{0.4}Co_{1-y}Fe_yO_{3-\delta}$ at high temperatures under controlled atmospheres

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Abstract

In order to develop a commercial SOFC system with high performance and long-term stability, it is important to understand heat distribution in the system. For this purpose, thermal properties of SOFC components should be understood, particularly under operating conditions, *e.g.* at elevated temperatures and under various oxygen partial pressures. In this study, thermal diffusivities of the perovskite-type oxides $La_{0.6}Sr_{0.4}Co_{1-y}Fe_yO_{3-\delta}$ ($0 \leq y \leq 1.0$, LSCF), which are a candidate of cathodes for intermediate temperature SOFCs, were studied. The samples were prepared by Pechini method, and confirmed by XRD to be single-phase with the perovskite-type structure. Thermal diffusivities of the LSCFs were investigated by using the laser flash method as a function of oxygen partial pressure, $p(O_2)$ (0.2 -10^{-4} bar), at temperatures from 873 to 1073K. It was found that the thermal diffusivity of LSCF significantly depended on oxygen partial pressure. The thermal diffusivity of LSCF decreased gradually as $p(O_2)$ decreased at all investigated temperatures, and decreased as temperature increased in the all investigated $p(O_2)$ range. The oxygen partial pressure dependence was larger in lower oxygen partial pressure and at higher temperature. These results indicated that the thermal diffusivity of LSCF was significantly affected by the oxygen nonstoichiometry change. The thermal diffusivity showed a one-to-one relation with the oxygen nonstoichiometry regardless of temperature, indicating the heat carriers were electron holes in LSCF.

B1015

Electrochemical Impedance Spectroscopy (EIS) on Pressurized SOFC

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Abstract

Former experiments at DLR on planar solid oxide fuel cell short stacks (SOFC) showed a considerable increase of performance at elevated pressure. This increase is due to numerous and interacting effects at both electrodes.

To fully understand this behavior it is not enough to characterize the short stacks only by current voltage curves. There needs to be further analysis by resistance measurements in order to obtain a better understanding. Electrochemical impedance spectroscopy (EIS) is a promising method to analyze the pressure-induced effects. A deduction from single cell results to stack results is hardly possible since stacks are mainly operated at higher fuel utilizations than single cells. EIS measurements on stacks have already been performed at ambient conditions but the influence of pressure can not be estimated by using stack results at ambient pressure.

Impedance spectroscopy showed that with increasing pressure the individual resistances and therefore the losses in the stack decrease.

This paper presents the results of the examination of a SOFC short stack at elevated pressures of up to 8bar with current voltage curves and impedance spectroscopy to examine the influence of pressure on the various resistances at OCV within the stack.

B1016

Impedance Simulations of SOFC LSM/YSZ Cathodes with Distributed Porosity

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Abstract

The cathode represents the main source of energy loss in hydrogen fed solid oxide fuel cells (SOFCs). In order to reduce the polarization resistance, porous composite cathodes, which consist of sintered random structures of electron-conducting (e.g., strontium-doped lanthanum manganite, LSM) and ion-conducting (e.g., yttria-stabilized zirconia, YSZ) particles, are often used. The optimization of the electrode performance requires the understanding of all the phenomena involved (e.g., electrochemical reaction, charge and gas phase mass transport) and how they interplay with the geometric and microstructural electrode features. Both mathematical models and impedance measurements are usually used to get this goal.
In this study, a mechanistic model for composite LSM/YSZ cathodes is presented. The model is based on mass and charge balances in transient conditions and accounts for the variation of porosity along the electrode thickness as experimentally observed on scanning electron microscope images. The continuum approach is used, which describes the composite structure as a continuum phase characterized by effective properties, related to morphology and material properties by percolation theory.
The model is used to simulate impedance spectra. Simulations allow a physically-based interpretation of experimental impedance spectra. The impedance simulations are performed by applying a sinusoidal overpotential with a specified frequency and solving the system of equations in time domain. The current density as a function of time is obtained as solution of the model and it is integrated in order to get the real and imaginary components of the impedance. The procedure is repeated for several frequencies. In this way, the modeled procedure reproduces the experimental method used to get the impedance spectra.
Simulated results are compared with experimental spectra for different electrode thicknesses (5-85μm) and temperatures (650-850°C). The comparison allows the evaluation of a macroscopic capacitance of the double layer at each interface LSM-YSZ, which is constant with electrode thickness. It is found that the low frequency arc (from 3.5 to 250Hz for temperatures respectively from 650°C to 850°C) is due to the double layer capacitance. However, there is not a clear relationship between the latter and the temperature, suggesting that the macroscopic capacitance gathers in itself several phenomena which have different behaviors with temperature.

B1017

A flexible modeling framework for multi-phase management in SOFCs and other electrochemical cells

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Abstract

Electrochemical energy storage and conversion technologies such as fuel cells and batteries are characterized by the presence of multiple solid, liquid and/or gaseous phases. These phases are central for the devices functionality:

(1) Chemical energy is stored within bulk phases (fuel cell: gaseous, battery: solid), while electrochemical reactions take place at the boundaries between phases
(2) Bulk phases are important for providing secondary functions, such as the provision of electronic and ionic conduction pathways in composite electrodes
(3) Solid phases play a key role in cell durability and cyclability, e.g., secondary phase formation in solid oxide fuel cells (SOFC) or complex phase formation-dissolution cycles in lithium-sulfur (Li-S) or lithium-air (Li-air) batteries

We present a generic framework for the modeling of multiple solid, liquid and/or gaseous phases in fuel cells and batteries. Basis is a multi-scale approach, which allows modeling transport and electrochemistry on three coupled scale regimes (1D channel + 1D electrode transport + 1D surface diffusion) [4]. It was enhanced by a multi-phase management, which allows for quantifying the evolution of an arbitrary number of phases. Phase formations as well as phase transitions can be described as chemical reactions. The evaluation of chemical source terms is carried out by CANTERA [11].

The effect of degradation processes, like secondary phase formation, on cell performance is represented by multiple mechanisms, like alteration of active surface area and triple phase boundary length or reduction of gas-phase/electrolyte diffusivity through the porous electrodes and by variation of the ionic conductivity. Simulation results will be presented for nickel oxide formation in SOFC anodes; the flexibility of the approach will be demonstrated by showing results from other applications as well (PEFC, Li-S, Li-air).

B1018

Surface Chemistry Studies and Contamination Processes at the Anode TPB in SOFC's using ab initio Calculations

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Abstract

The chemical processes that occur at the anode triple phase boundary (TPB) between Ni, YSZ and fuel molecules is essential as they play a key role in determining solid oxide fuel cell (SOFC) anode performance. In this study, the problems relating to surface chemistry occurring at the anode TPB in a solid oxide fuel cell are investigated. We report preliminary work using first principles atomistic simulations based on density functional theory (DFT) to model the surfaces of Nickel and YSZ and construct a model of the interface between them and the gas phase. Our initial results in this area are presented.

B1019

Electrical and Mechanical Characterization of $La_{0.85}Sr_{0.15}Ga_{0.80}Mg_{0.20}O_{3-\delta}$ Electrolyte for SOFCs using Nanoindentation Technique

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Abstract

$La_{1-x}Sr_xGa_{1-y}Mg_yO_{3-\delta}$ (LSGM or LSGM1520, for x = 0.15 and y = 0.20) is one of the most commonly used electrolytes for SOFC applications at intermediate temperatures (600-800ºC). In the present work, we report the preliminary results on the electrical and mechanical properties of LSGM1520 electrolyte. First of all, LSGM disks (*Ø* = 5 mm and *thickness* = 200 µm) were prepared by cold isostatically pressed and sintered at 1300, 1400 and 1500ºC, from ceramic precursors obtained by the polymeric organic complex solution method. Afterwards, the electrical properties were determined by impedance spectroscopy in order to evaluate the usefulness of the LSGM1520 obtained as an electrolyte for SOFC application. Mechanical properties, such as Elastic modulus (*E*) and hardness (*H*), were studied by Nanoindentation technique. Thus, *E* and *H* were determined from loading/unloading curves at different applied loads: 5, 10, 30, 100 and 500 mN, using the Oliver and Pharr method.
The preliminary results indicated that electrical measurements evidenced reasonable ionic conductivities, around 0.01 $S \cdot cm^{-1}$ at 800°C, which were comparable to those reported in literature for the LSGM prepared by different synthesis methods. The mechanical properties of interest presented almost constant values, around *E* = 260 ± 7 GPa and *H* = 12.4 ± 0.8 GPa, respectively, for indentation applied loads higher than 30 mN.

B1021

A Model of Anodic Operation for a Solid Oxide Fuel Cell Using Boundary Layer Flow

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Abstract

Understanding the effects of the development of a boundary layer past a body is of particular interest to many industrial problems such as aerodynamics. Extending this theory to reactive boundary layers is of specific practical interest to applications such as bluff body flame stabilization and fuel cell operation.

In this model we will consider the flow of humidified hydrogen over a flat, semi-infinte, impermeable plate which is coated with a catalyst. In a thin region close to the plate a viscous boundary layer forms due to the fluid adhering to the solid boundary. Within this region the viscosity of the fluid is comparable or more significant than the diffusivity of fuel and oxidants. Furthermore, the fluid flow becomes coupled with the convection-diffusion equations for the bulk flow, within the boundary layer, and on the surface the flow becomes coupled with the electrochemical kinetics that occurs in fuel cell operation.

We will present an asymptotic solution to the described model near to the leading edge of the plate where a naturally occurring singularity is present within the flow. Analysis of singularities in fuel cells and fuel cell systems is uncommon but must be treated with great importance due to the uncertainty of the use of the model equations within this region. As a result of the singular nature of this problem we use the asymptotic solution as an initial condition to the full numerical solution of the problem. An overall comparison between the numerical solution and asymptotic solution shows a good agreement which validates the numerical solution near to the singularity.

Furthermore, we present the dependence of the mass fractions of species on the current density of the cell and we demonstrate how the I-V curves vary with respect to cell position and how certain overpotentials, in particular the activation overpotenial, vary with respect to current density and cell position.

B1022

Numerical Analysis on Dynamic Behavior of a Solid Oxide Fuel Cell with a Power Output Control Scheme: Study on Fuel Starvation under Load-following Operation

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Abstract

The characteristics prediction of Solid Oxide Fuel Cell (SOFC) dynamic behavior is considerable subject in the SOFC development toward practical use. The power generation performance of SOFC can be governed by multi time scale of the transport phenomena, such as electron transport, gas diffusion and heat transfer. They can be restrictions on favorable SOFC operation. Hence the control scheme must be built considering those unsteady characteristics. Previously load-following capability of the SOFC adopting internal fuel reforming system, it was shown building power output control scheme with current manipulation. The control tactics of fuel utilization factor, steam-to-carbon ratio and cell operating temperature were adopted with the power output control scheme and then whole control system achieved the stable and efficient SOFC operation. The result showed an importance of the thermal management leading to higher power generation efficiency. However, there is still specific restriction remained for the actual operation. One of the considerable restrictions is known as fuel starvation. The fuel starvation can be accompanied by the rapid increase of the current. Thus, the prevention to avoid the fuel starvation is essential for safe SOFC operation.
The present paper focuses on the dynamic simulation of the SOFC, which includes an indirect internal fuel reformer, in order to predict the fuel starvation occurrence under load-following control. The study also aims to propose the prevention method of the fuel starvation. From this viewpoint, the relation of the fuel utilization factor and the cell operating temperature controls to the prevention of the fuel starvation were studied. It was predicted that the fuel starvation occurs due to the rapid increase of fuel consumption caused by drastic current change for the power output control. Both of the fuel utilization factor and the cell operating temperature controls contributed to the prevention of the fuel starvation. The fuel utilization factor control extends the available range of the current manipulation and also contributes to the restraint on the variation of the cell operating temperature. The cell operating temperature management brings the smaller current manipulation. Thermal management has strong effect on the transient capability of the SOFC. Considering the SOFC I-V characteristic, which depends strongly on the operating temperature, the cell operating temperature management is a significant issue not only in terms of highly efficient operation but in terms of safe operation avoiding fuel starvation.

B1023

3D Effective Conductivity Modeling of Solid Oxide Fuel Cell Electrodes

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Abstract

The effective conductivity of a thick-film solid oxide fuel cell (SOFC) electrode is an important characteristic used to link the microstructure of the electrode to its performance. With the development of increasingly accurate three dimensional (3D) imaging methods of fuel cell microstructures by destructive (e.g. focused ion beam) and non-destructive (e.g. X-ray tomography) techniques, we are now capable of analyzing more effectively the relationship between microstructural characteristics and overall cell performance. A 3D resistance network model has been developed to determine the effective conductivity of a given SOFC electrode microstructure. This paper presents an overview of the functionality of the 3D resistance network model alongside a comparison of resistance data with analytical results from literature and commercial software packages. A given 3D SOFC anode microstructure reconstructed from imaging processes is initially discretized into voxels, typically 1/25th the size of a nickel particle, based on which a mixed resistance network is drawn. A potential difference is then applied to the network which yields by mathematical manipulation the corresponding current, finally allowing for the equivalent resistance of the entire structure to be determined.

B1025

Performance Artifacts in SOFC Button Cells Arising from Cell Setup and Fuel Flow Rates

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Abstract

Button cells are widely used by the SOFC research community. However it can be seen that only a little emphasis has been given to the relationship between fuel flow rates, cell setup, and cell performance when reporting results for SOFCs conducted on button size cells. When OCVs are reported that are significantly less than theoretical OCV, this loss in potential has usually been attributed to pinholes in the SOFC or seal leaks that would allow mixing of fuel and oxidant. Also, especially due to its high operating temperature, mass transfer above the electrode surface is considered as govern by convective mass transfer. Therefore, concentration polarization is defined as cell voltage loss due to mass transport limitations inside the porous electrodes, and all mass transfer related losses outside the electrode surfaces are considered negligible. Bessler [1], in modeling SOFC impedance, introduced a term called “Gas Concentration Impedance” as a result of a stagnant gas layer on top of the electrode surface, which could be considered an artifact due to button cell test setup. According to Bessler, gas concentration impedance is the resistance experienced by gases diffusing through the stagnation layer and it is a function of gas inlet velocity and standoff distance. Chick et al.[2] presented experimental evidence supporting Bessler’s conclusion about the effects of standoff distance in button cell research. In this work, we provide experimental evidence to support Bessler’s predictions about the effects of inlet velocity on button cell test arrangement. Evidence is presented that eliminates leaks and pinholes as possible causes of reduced OCV and cell performance.

B1026

Modeling of Current Oscillations in Solid Oxide Fuel Cells

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Abstract

Fuel cells have been known to exhibit an oscillatory electrical output in either potentiostatic or galvanostatic mode. The onset of these oscillations has generally been controlled by adjusting the operating conditions such as temperature, bulk concentration of reactants and applied current or voltage. The model that has been developed explains the mechanism behind the oscillations in current for a solid oxide fuel cell run on a methane/hydrogen mixture. The electrical output is associated primarily with the hydrogen which is oxidised at the anode surface, thus a lumped model of this region was introduced. Rate equations were derived from the reaction scheme and reduced to a 2D dynamical system. Initially an assumption of dry conditions was implemented and analysis shows the appearance of a limit cycle due to a hopf bifurcation, which is associated with the oscillatory output. Numerical investigation indicates that the amplitude of the limit cycles increase further from the hopf point until the occurrence of a homoclinic bifurcation. The diffusivity and initial concentration of methane are seen to be key parameters of the system.

B1027

Parametric Study of Single-SOFCs on Artificial Neural Network Model by RSM Approach

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Abstract

Parametric study is performed by experimental design (DOE) approach for solid oxide fuel cells (SOFCs) on an artificial neural network (ANN) model of the SOFC performance. The effects of cell parameters, i.e. anode supported layer thickness, porosity, electrolyte thickness, and cathode functional layer thickness, are calculated to recognize the significant factors. Moreover, Interaction effects of the cell parameters are also determined and finally optimal cell parameters in the range of them are found at the highest performance by response surface methodology (RSM) approach.
The results of this analysis are determined the most significant parameter of single-cells of the SOFCs. The optimum MPD of the SOFC in the current paper is calculated for the single-cell with the cell parameters. Therefore, this novel approach can be used to recognize the effects of the cell parameters of the SOFCs and increase the performance in the optimal design of cell

B1028

Electronic Structure in Degradation on SOFC.

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Abstract

The depth profile of electronic structure has been probed by soft X-ray absorption technique from interface with electrolyte side in Cathode material, LaSrMnO3 functional layer. The sample had been exposure at 900 degree for 10,000 hours under real SOFC operation environment with fuel and hydrogen supplied. As figure 1 shows, the signals from oxygen NEXAFS at Beam Line 7.011 in Advance Light Source were collected as electron yield which comes from photon current at LSMO surface with around 20A depth. From the results in fig 1 left, the intensity of pre-edge around 534 meV, which should be contribute from eg band in LSM structure, decrease and move to lower energy value as function of thickness. These results suggest that there are fewer unoccupied states in eg band than in that of thicker position due to extra electrons doped into the eg band of LSMO. Those extra electrons doped maybe come from the chemical contamination and then lead to increasing the electronic resistivity as function as operation time.

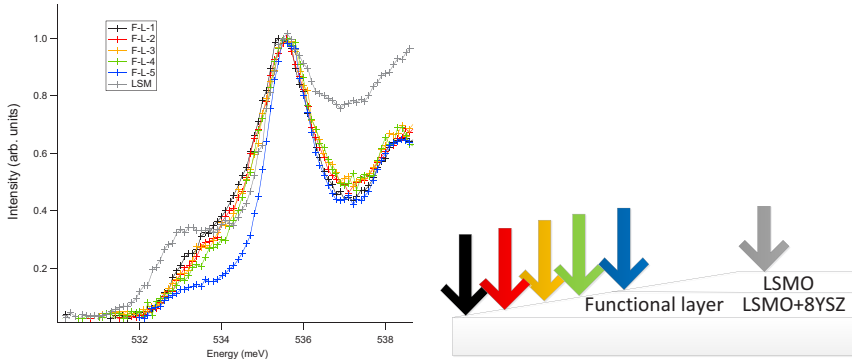

Figure 1, left, the Oxygen NEXAFS of LaSrMnO3 functional layer as functional of thickness. Right, the sketch for detecting point at different depths at functional LSMO layer.

B1029

Computational Fluid Dynamic evaluation of Solid Oxide Fuel Cell performances with biosyngas under co-flow and counter-flow conditions

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Abstract

Fuel cells, which convert the chemical energy stored in a fuel into electrical and thermal energy, offer an efficient solution for efficient and low pollution production of electricity and heat. These devices rely on the combination of hydrogen and oxygen into water: oxygen is extracted from the air while hydrogen can be obtained from either fossil fuels or renewable sources. Solid Oxide Fuel Cells (SOFCs) are often designed to operate with specific fuels, quite often natural gas. Hydrogen can also be internally produced inside the fuel cells from the reforming reaction of methane. Internal reforming has a crucial impact on the performance of SOFCs, especially on the current density, temperature distribution and the resulting thermal-stress. Computational Fluid Dynamic (CFD) modeling is often used to arrive at efficient and safe SOFC designs. An SOFC design developed by ECN together with Delft University of Technology is employed for the calculations. The impact of different fuels on the cell performance has been studied in our previous work. However, the performances under co-flow and counter-flow operations are still unknown. Model results provide detailed profiles of temperature, Nernst potential, anode-side gas composition, current density and hydrogen utilization over a range of operating conditions. Variations in temperature distribution and species concentration are discussed. Quite interesting results are observed for the current density variations when different fuels are used. Detailed results from the CFD calculations for a single channel are presented. Thermal predictions of nickel oxidation and carbon deposition and temperature gradients are employed to detect the operation safety. The fuel cell designed for methane as a fuel is also shown to be safe for operation with biosyngas both under co-flow and counter-flow conditions.

B1030

A numerical analysis of the effect of a porosity gradient on the anode in a planar solid oxide fuel cell

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Abstract

The phenomenon of a porosity gradient on an anode in an intermediate temperature solid oxide fuel cell (IT-SOFC) was be analyzed by a comprehensive model combined with relevant theoretical and experimental data. The numerical simulation is useful in understanding the factors related to the performance of the change in anode morphology of an IT-SOFC. In this research, the factor considered was the porosity gradient developed in an anode. The effects of temperature, gas flow and concentration of the catalyst were fixed. The triple-phase boundary (TPB) and porosity were, thus, changed by the porosity gradient on the anode.
A planar type anode-supported IT-SOFC with a porosity gradient was fabricated using tape casting, including hot pressing lamination. The single cell consisted of a Ni/YSZ cermet anode, 8mol%YSZ electrolyte, and lanthanum strontium manganite (LSM) cathode. Scanning electron microscopy (SEM) revealed a crack-free and dense electrolyte in the single cell. The open circuit voltage (OCV) of the single cell exhibited good performance, and demonstrated that a concentration distribution of porosity in the anode increases the power in a single cell. The simulation identified that the primary effect on the single cell with a porosity gradient between the TPB and the gas transportation is the related to electrochemical activation overpotential and concentration overpotential.

B1101

Electrochemistry of Reformate-Fuelled Anode-Supported SOFC

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Abstract

An overall understanding of the electrochemical processes which determine the performance of reformate-fuelled SOFC anodes has not been reported in literature yet. In our previous study, we performed a detailed kinetic analysis of the electrochemical oxidation of reformate fuels within SOFC-anodes [1]. Building on experience acquired there, this study presents a detailed analysis of the gas transport polarization processes occurring in reformate-fuelled SOFC-anodes via electrochemical impedance spectroscopy (EIS).

The presented analysis was carried out on state of the art anode-supported single cells with an active electrode area of 1 cm². Operation with model reformate fuels (consisting of H_2, H_2O, CO, CO_2 and N_2 at chemical equilibrium) enabled experiments under defined gas concentrations within the anode substrate. The recorded electrochemical impedance spectra were analyzed with the distribution of relaxation times (DRT) method [2] and subsequent CNLS-fitting [3], which allowed for the deconvolution and accurate quantitative analysis of the individual electrochemical polarization processes.

EIS measurements performed under a systematic variation of the fuel gas composition lead to the unambiguous identification of the physical origin of the two low-frequency polarization processes reported for reformate operation: the polarization process P_{1A} is originated by H_2/H_2O-transport in the gas pores of the anode substrate, while the process P_{ref} is dominated by CO/CO_2-transport. Furthermore was demonstrated that the water-gas shift reaction itself does not cause a single polarization process. These results have been confirmed by a poisoning study [4], where the CO-conversion through the water-gas shift reaction was poisoned by introducing 0.5 ppm H_2S to the anode fuel gas. The observable drastic decrease of P_{ref} confirmed that this process is dominated by the gas-phase transport of CO/CO_2; the notable increase of P_{1A} confirmed that this process is originated by the gas-phase transport of H_2/H_2O.

B1102

Reforming and SOFC system concept with electrical efficiencies higher than 50 %

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Abstract

Improving the electrical efficiency of LPG or natural gas based SOFC systems offers a high potential for residential and other stationary applications. Furthermore a CHP coefficient higher than 1,0 leads to a possible continuous operation as heat and power supply even in summer in low-energy houses eliminating the SOFC-technology drawback – the limited number of start/stop-cycles.
As complete internal reforming of the feedstock leads to thermal stresses in the SOFC a system layout has to be designed with external reformer ensuring electrical system efficiency higher than 50 %.
This paper is focused on a simple system design with an el. power output of 1 kW consisting of the SOFC, a reformer, a burner, a recuperator and a recirculation device for the anode off-gas (AOG) as major components. Depending on the ability of partly internal reforming in the SOFC the reformer is designed as adiabatic pre-reformer or as reformer convectively heated by the exhaust gas. For both system configurations thermodynamic simulations have been made with the focus on the boundary conditions of carbon formation and system efficiencies. In case 1 natural gas is supplied to an adiabatic reformer. In case 2 a convectively heated reformer is fed with propane. Tests have been performed with the convectively heated reformer at different operation conditions resulting in a good agreement between thermodynamic simulations and experimental results. No carbon formation could be detected in the reformer.
System designs, simulation results and thermodynamic calculations for both system configurations demonstrating electrical system efficiencies higher 50 % and CHP coefficients higher 1 will be presented in this paper. Furthermore experimentally determined performance data of the convectively heated reformer (case 2) and the adiabatic burner will be shown.

B1103

Minimising the Sulphur Interactions with a SOFC Anode based on Cu-Ca Doped Ceria

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Abstract

One of the major challenges for the direct use of hydrocarbon fuels in solid oxide fuel cells (SOFCs) is the poisoning of common Ni-based anodes by coke formation and the impurities such as sulphur in readily available hydrocarbon fuels. It is well known that carbon formation could be avoided by replacing Ni with electronic conductors but it is still constantly reported that even trace amounts of sulphur content in the fuel causes a dramatic decrease in the SOFC performance. Ceria serves successfully as a H_2S adsorbent and is used as a sulphur-removal material, as well as to have good hydrocarbon oxidation activity. Thus, Cu-ceria anodes compared to the standard composites could be an attractive solution.

We have previously shown that the incorporation of calcium to the microstructure of Cu-CeO_2 nanopowders increases the ionic conductivity and consequently the total electrical conductivity what significantly improves the global cell performance running with H_2 and/or methane. Single cell was prepared using samaria doped ceria (SDC) as electrolyte, commercial LSM paste as cathode and Cu-Ca doped ceria (40 at.% Cu and 10 at.% Ca; prepared by coprecipitation within reverse microemulsion) as anode.

In this context, the present work explores the electrode behaviour of the Cu-Ca doped ceria anode in H_2S-containing fuels. Different sulphur tolerance tests in dry and humidified hydrogen (up to 1000 ppm H_2S) were carried out and analysed in order to elucidate the reactions of hydrogen sulphide at the anode. The main objective is the characterisation of this formulation at structural level upon interaction with H_2S as well as with regard to changes taking place in the system. X-Ray diffraction as well as Raman and XPS spectroscopies give evidence of the total transformation of this anode material in the presence of H_2S-containing dry hydrogen to form different metal and cerium oxysulphides. However, the incorporation of steam to the fuel composition minimises the formation of these sulphur compounds and anode material practically maintains its original morphology and structure after the exposure to H_2S-containing humidified hydrogen (500 ppm H_2S).

Single cell tests endorse this approach and demonstrate the ability of Cu–Ca doped ceria anode to directly operate on H_2S-containing hydrogen and methane fuels at relative low temperature (1023 K).

B1104

Gas Transport and Methane Internal-Reforming Chemistry in Ni-YSZ and Metallic Anode Supports

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Abstract

Solid-oxide fuel cell (SOFC) developers utilize very different macro- and microstructural design strategies to create optimal anode supports. The macro- and microstructural characteristics of the support, and the support materials, have a great impact on the transport of reactive gases to and from the triple-phase boundary regions, and the internal-reforming processes underway within the porous support structure. In this work, we describe a unique tool for investigating the dependencies between the structure and morphology of the anode support, and the resulting gas transport and internal-reforming chemistry within the support. In this work, the Separated Anode Experiment is used to characterize and compare performance of Ni-YSZ cermet anode supports fabricated by two leading developers (CoorsTek, Inc., Golden, CO, USA and Risø-DTU, Lyngby, Denmark). Ferritic-steel supports fabricated by PLANSEE SE (Reutte, Austria) are also examined.
The Separated Anode Experiment has been developed to decouple thermochemical and electrochemical processes underway in solid-oxide fuel cell anode supports. A single channel of an SOFC is simulated by sealing an anode support between two ceramic manifolds into which flow channels have been machined. The assembly is placed within a furnace and heated to SOFC operating temperatures. Gases representative of hydrocarbon fuel streams are fed into the “fuel channel”, while the opposite “electrolyte channel” is fed with gas mixtures representative of the products of electrochemistry (H2O and CO2). These gases are free to cross-diffuse through the porous anode support and participate in internal-reforming reactions. Exhaust-gas compositions are measured using gas chromatography. A computational model is used to aide in interpretation of experimental results, and for design of optimized support architectures.
The different materials, macrostructures and microstructures of the CoorsTek, Risø-DTU, and PLANSEE materials result in significant differences in performance. The open pore structure of the CoorsTek support enables high rates of gas transport, while the tight morphology of the Risø-DTU support lends itself to a comparatively high level of methane internal reforming. The large pore sizes of the PLANSEE metallic support also result in high gas transport, but the iron-chromium composition leads to little methane internal reforming. This motivates use of the computational model for design of Ni-YSZ anode functional layers for the PLANSEE metal support, yielding a reasonable level of internal reforming.

B1105

High efficient biogas electrification by an SOFC-system with combined steam and dry reforming

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Abstract

Power generation from biogas using motor-driven CHP units suffers from electrical efficiency far below 50 %, especially in the power range below 100 kW_e. Fluctuating quality and/or low CH_4 content reduce operation hours and economical and ecological benefit.
Solid oxide fuel cell (SOFC) systems provide electrical efficiencies above 50 % even for small-scale units and/or low-calorific biogas. SOFC-stacks are not available in the hundreds of kW_e range yet and they need further improvements regarding their fuel efficiency, costs and lifetime. Nevertheless commercial state-of-the-art stacks and stack modules are already established in the market and thus available for the evaluation of different system concepts.
In collaboration with The fuel cell research center ZBT GmbH (ZBT), Duisburg, CUTEC has developed and built a biogas operated 1 kW_e SOFC-system based on combined dry and steam reforming of CH_4. A commercial SOFC stack module with two 30-cell ESC-stacks was used. Both, synthetic biogas mixtures and biogas from the wastewater facility of a sugar refinery were used as fuel. To assure a H_2S concentration < 1 ppmv in the clean gas a sulfur trap was designed on the basis of three earlier biogas monitoring campaigns.
The system was characterized in the laboratory and subsequently operated on the biogas plant. Electrical power output of 850 to 1,000 W_e and electrical gross efficiencies between 39 and 52 % were received for CH_4 contents between 55 and 100 Vol.-%. Fluctuations in the biogas composition are compensated by the system control. These results were confirmed with synthetic biogas containing 55 Vol.-% CH_4 proving an electric power output of 1,000 W_e and an efficiency of 53 %. No degradation of the stacks or the system components could be observed during the 500 h test period.

B1106

ADIABATIC PREREFORMING OF ULTRA-LOW SULFUR DIESEL: POTENTIAL FOR MARINE SOFC-SYSTEMS AND EXPERIMENTAL RESULTS

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Abstract

Solid oxide fuel cells (SOFC) promise improvements towards efficiency and emission. The choice of fuel processing method like the catalytic partial oxidation, autothermal reforming or steam reforming strongly affects the system efficiency and power density. Adiabatic prereforming of logistic fuels is one of the most attractive solutions for planar SOFCs. Electrical system efficiencies of around 55% are expected for SOFC systems on oceangoing ships. Furthermore, the SOFC system is expected to be 20% to 30% more compact than a SOFC system involving a fired steam reformer operating at around 800°C. On the other hand, adiabatic prereforming at around 500°C is more challenging towards deactivation by sulfur. Logistic fuels like diesel or jet fuel can be desulfurized with a manageable effort down to a similar sulfur level as Ultra-Low Sulfur Diesel (ULSD) with 10 ppm wt. The ability to convert logistic fuels with 10 ppm wt. sulfur within an adiabatic prereformer is thus a prerequisite to avoid any deep desulfurization technologies and keeping thereby the system simple and efficient.

In this context, various long term tests have been carried out with one of Haldor Topsoe's catalyst. The prereformer has been operated on ULSD. A reformate composition with above 40% hydrogen (dry base) has been demonstrated without any traces of higher hydrocarbons for more than 500 hours. The reformate composition was measured online and condensate samples were taken in fixed intervals. No higher hydrocarbons were observed as liquid phase on top of the samples. The results reflect the high potential of adiabatic prereforming for mobile SOFC systems utilizing logistic fuels.

B1108

Fuel Processing in Ceramic Microchannel Reactors for SOFC Applications

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Abstract

Effective operation of practical solid-oxide fuel cell (SOFC) systems relies upon heat exchangers and chemical reactors. System efficiency can be improved and cost reduced by combining unit processes into single components. This work describes a ceramic microchannel reactor that achieves process intensification by combining heat-exchanger and catalytic-reactor functions to provide high-quality syngas to the SOFC stack.

Microchannel heat exchangers and reactors can deliver very high performance in small packages. Such heat exchangers are typically fabricated from stainless-steel metal sheet using diffusion-bonding processes. Ceramic microchannel reactors offer some significant advantages over their metallic counterparts, including very-high-temperature operation, corrosion resistance in harsh chemical environments, low cost of materials and manufacture, and compatibility with ceramic-supported catalysts.

In this work, reactor design is based on the results of three-dimensional computation fluid dynamics (CFD) simulations using ANSYS/FLUENT. Models include the conjugate heat transfer between fluid- and solid-phase materials, and are used to create a design that achieves high reactor performance while meeting the unique requirements of the reactor-fabrication process. This CFD model has been coupled with CHEMKIN, a powerful chemical-kinetics modelling tool, to include simulation of chemically reacting flow. The current reactor design utilizes four layers of microchannels. Inert heat exchange in two of the layers provides thermal energy to drive methane steam-reforming reactions on the other two catalyst-coated layers. The reactor body is fabricated by CoorsTek, Inc. (Golden, CO, USA) using 94% alumina and high-volume-manufacturing methods. High-temperature co-sintering of the four layers results in a single hermetically sealed polycrystalline ceramic body. Catalytic activity is enabled by washcoating a rhodium catalyst over an alumina-ceria oxide support structure deposited within the reactor.

Heat-exchanger effectiveness of up to 88% has been demonstrated. Reactive heat-exchanger testing has been completed on steam reforming of methane with 90% methane conversion and high selectivity to syngas. Experimental results are validated and interpreted using the ANSYS/FLUENT model.

B1109 (Abstract)

Electro-catalytic Performance of a SOFC comprising Au-Ni/GDC anode, under varying CH_4 ISR conditions

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Abstract

In view of the fact that natural gas, which contains CH_4 as its main component, is a key energy vector worldwide the operation of SOFCs under internal reforming or direct oxidation conditions is very important. The present work refers to the study of the electrocatalytic performance of a cell that comprises Ni/GDC as anode functional layer, which has been modified via the deposition of Au nano-particles. The cell was tested under different H_2O/CH_4 ratios, in order to study the effect of varying CH_4 concentration on the electrocatalytic activity of the anode. Interestingly, at high H_2O/CH_4 ratios the cell shows low catalytic and electrocatalytic activity in terms of H_2 and CO production. In addition, as the current density increases both H_2 and CO production rates decrease, which is attributed to the electrochemical oxidation of H_2 and CO to H_2O and CO_2, respectively. On the other hand, the decrease of the H_2O/CH_4 ratio to 0.25 is followed by the increase of the catalytic activity and the faradaic increase in the electrocatalytic production rates of H_2 and CO and the lack of CO_2 formation. This can be attributed to the partial electrochemical CH_4 oxidation. It must be also noted that no carbon deposition was detected on the Au-Ni/GDC anode under these CH_4 rich conditions.

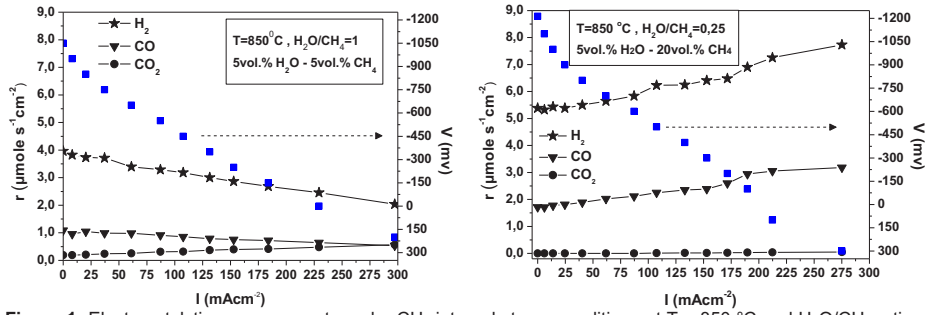

Figure 1: Electrocatalytic measurements under CH_4 internal steam conditions at T = 850 °C and H_2O/CH_4 ratios: 1 and 0.25, for a cell with 1wt.% Au – Ni/GDC as the anode functional layer.

This work has been carried out within the framework of the **ROBANODE** project (Joint Technology Initiative-Collaborative Project), which is financially supported by the **European Union** and the **FCH-JU**.

B1110

Performance of Tin-doped micro-tubular Solid Oxide Fuel Cells operating on methane

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Abstract

Carbon coking is a well known problem when utilizing hydrocarbons directly, through internal reforming on Ni-YSZ anodes. To reduce coking on anode supported micro-tubular SOFCs (mSOFCs) operating on methane, tin-doping was carried out on the porous surface of NiO/YSZ. The mSOFCs utilised had a 2.3mm diameter and 55mm length, 200µm thick NiO/YSZ anode support, 15µm YSZ electrolyte and 20µm LSM cathode offering 1 cm^2 active surface area. The cells were tested on 5 ml/minute CH_4 fuel mixed with 20 ml/minute inert Helium gas. Tin-doped cell produced the highest power density of 440mW/cm^2 which was reached at 0.530V and 830mA/cm^2, while un-doped cell produced a maximum of 300mW/cm^2 which was obtained at 0.45V voltage and 660 mA/cm^2. At 0.7V constant voltage and 800°C operating temperature the tin-doped cells gave an average of 320mW/cm^2 power density while the un-doped cells gave 220mW/cm^2. Furthermore, after operating for 5 hours the tin-doped cells showed 11% power degradation while the un-doped cells showed 25% degradation. Results of SEM and EDX on the anode surface before and after cell tests showed that there was much lower carbon deposition detected on the tin-doped cells compared to that on the un-doped cells. This showed that the tin-doped cells have ability to reduce coking. The conclusion from this work shows that mSOFC's can be successfully doped with tin to reduce the effects of carbon deposition resulting in a greater than 50% reduction in degradation rates. Further work is required to verify these findings over a longer time frame and understand the coking mechanism & cell degradation behavior.

B1112

OXYGENE project - summary

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Abstract

OXYGENE was a project jointly realised by GDF SUEZ Research and Innovation CRIGEN, CEA LITEN and three university laboratories: SIMAP, LEPMI and IJLRA. It was sponsored by ANR, the French Research Funding Agency, through its HPAC 2008 program on Hydrogen and Fuel Cells. The two limitations of SOFCs operations were addressed in this project by the means of coupling modelling and experimental approaches. The first approach was dedicated to studies of the performance and degradation under CH_4 operations without reforming on commercially available anode supported Ni/YSZ cermet SOFC structures. The second approach focused on estimation of the cell tolerance upon re-oxidation under a steam. The project was initiated in January 2009 and is scheduled to terminate in December 2011. The goal of this project was achieved by the following studies:

- Measurement of oxidation rate between 500 and 900°C under different P_{O_2} (0.3, 1, 5, 10 and 20% O_2),
- Measurement of the expansion upon re-oxidation, Young modulus, and creep rate of the cermet,
- Simulations of Ni/YSZ re-oxidation process and cell failure prediction,
- Insight into the shutdown protocol,
- Fuel utilisation studies (fuel flow and current density relations),
- Morphologic properties of the cermet, and
- Ageing of the cell.
-

The ageing experiments were done on commercially available Ni-YSZ anode support cells, supplied by the FZJ Company. Series of tests were performed at 800 ˚C under 0.6 A/cm^2, first under Hydrogen and then under Methane with steam to Carbon ratio of 1. These studies resulted in creation of a tool simulating CH_4 operations, oxidation, creep and fuel utilisation. The validity of the model was partially validated experimentally. This tool allows for more accurate operations and shutdown protocols for SOFC.

B1113

Experimental investigation on the cleaning of biogas from anaerobic digestion as fuel in an anode-supported SOFC under direct dry-reforming

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Abstract

Biogas produced from dry anaerobic digestion of the Organic Fraction of Municipal Solid Waste (OFMSW) in a pilot plant, is monitored in composition. Impurities, even those present only in traces, are detected through a direct injection mass spectrometry technique known as Proton Transfer Reaction – Time of Flight – Mass Spectrometry (PTR-ToF-MS). VOCs detected (mostly sulfur compounds) showed that a gas cleaning stage is certainly required in order to feed the biogas to an SOFC cell, even during the central weeks of production, when the biological activity within the reactor yields the lowest concentrations of impurities. A gas cleaning unit exploiting the adsorbent properties of activated carbon particles, impregnated with copper and iron, is used to produce a clean biogas stream suitable to feed directly commercial planar anode-supported cell based on Ni. Since small amount of H_2S are likely to flow through the cleaning section, it is relevant to study the impact of small ppmv amount of sulfur on the operation of the SOFC running directly on the biogas. A simulated biogas stream(CH_4/CO_2) with/without known amount of H_2S (in term of ppmv) and the addition of O_2 to promote the conversion of CH_4 to H_2 and CO via partial oxidation (POx) was feed to an anode-supported SOFC. to investigate the effect of ppmv-level hydrogen sulfide on the direct dry-POx reactions occurring within the anode compartment. For the selected bio-CH_4/oxidant mixture, a stable behavior of the cell voltage under a load of 0.5 A cm^{-2} was observed for more than 200 h at 800 °C. Oxygen addition, in a sulfur free biogas mixture – as it would be available from the cleaning section with activated carbon filtration – demonstrated itself to be effective to prevent C-deposition and to promote an efficient conversion of the methane into H_2 and CO. Whereas the presence of 1 ppm in the biogas stream brought a decay of the cell performance, fully recovered once the sulfur was removed.

B1114

Design and Manufacture of a micro Reformer for SOFC Portable Applications

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Abstract

This work describes the design and fabrication of a micro reactor based on silicon technology for the generation of hydrogen by reforming ethanol steam. Ethanol has been chosen as a fuel since can be obtained from renewable biomass, has a very high energy density and it is easy to handle and store. The reformer has been designed as a silicon micro monolithic substrate compatible with the mainstream microelectronics fabrication technologies (photolithography, wet etching, chemical vapor deposition and reactive ion etching). Moreover, materials compatible with silicon micro fabrication have been selected, ensuring the thermal and chemical stability of the device. Design and geometry of the system have been optimized for minimizing heat losses in order to satisfy the high temperature requirements of the reforming process. The micro reformer consists of an array of more than $4.6 \cdot 10^4$ vertical micro channels perfectly aligned (50μm diameter) and an integrated serpentine tungsten (W) heater. This micro channels contain the support and catalyst for the reforming. The current design has dimensions of 15x15 mm^2 in area, 500μm in thickness and an effective reactive area of more than 36 cm^2. This huge contact area between fuel gas and catalyst, leads to a high performance in small volumes. At a working temperature of 550ºC, we expect hydrogen production of $6.6 \cdot 10^{-3}$ ml/min able to power a micro-SOFC of 1W during 24h for a tank capacity of 9.5 ml of ethanol.

B1115

Experimental evaluation of a SOFC in combination with external reforming fed with biogas. An opportunity for the Italian market of medium scale power systems.

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Abstract

The biogas is one of the most known and widespread renewable fuels, obtained from a variety of biomasses such as degradation of urban and industrial waste, landfills, co-digestion of zootechnical effluents, agricultural waste and energy crops. In Italy, where “Green Certificate” has been adopted, there is new interest for biogas plants. The biogas composition is related to the starting substrate but basically it consists of 50-75% CH_4, 25-45% CO_2, 2-7% H_2O (at 20-40 °C), 2% N_2, <1% H_2 and H_2S, traces of O_2, NH_3, halides and siloxanes. At present, in Italy, biogas is mainly used to produce electricity and heat by cogeneration systems, internal combustion engines (ICE) and gas turbines represent the most employed technology. This study deals with an investigation of the performances of biogas (CH_4= 60%, CO_2 = 40%) fed state-of-the-art SOFC in combination with an external tri-reforming system. The tri-reforming has been carried out using a catalyst based on 1.75 wt. % of Ni in CeO_2 ($Ce_{0.95}Ni_{0.05}O_2$) and varying the O_2/CH_4 and the H_2O/CH_4 molar ratio values in order to establish the influence of different syngas composition on the integrate SOFC + reforming performance. It aims to demonstrate that a state-of-the-art anode based SOFC can tolerate the feed of different percentages of H_2, CO, CH_4 and CO_2 without the need of steam addiction in the cell. The SOFC performance and efficiency achieved by the integrated system appeared well self-consistent with the thermodynamic prediction of the electrochemistry for the different syngas composition obtained from the tri-reforming of biogas. The results suggest that the tri-reforming in combination with state-of-the-art SOFC can be considered an immediate settlement for small and medium sized stationary power systems.

B1116

Fuel Variation in a Pressurized SOFC

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Abstract

The demand for electrical energy is growing continually. In order to meet this demand in future, power plants with high efficiency and low emissions are needed. For example a hybrid power plant consisting of an SOFC system combined with a gas turbine which offers electrical efficiencies of up to 60% at a wide range of applications from kW to MW. One major advantage of this combination is that it can be operated amongst others on natural gas from the existing grid. Efficiencies have been shown to be highest if the SOFC subsystem is pressurized. This and the requirements due to the interaction with the gas turbine lead to a need to exactly understand the behavior of SOFC at elevated pressures. The German Aerospace Center (DLR) is aiming to demonstrate stable operation of such a hybrid power plant and is currently examining the behavior, requirements and limits of the subsystems at elevated pressure.

A test rig for the examination of pressurized SOFC [3] exists at DLR to examine various planar stack designs at elevated pressure which has so far been used to asses the influence of pressure on performance with different fuels at different temperatures. Experimental results have been used for validation of a cell model which allows for a thorough interpretation of the experimental data and a qualitative prediction of stack behavior under other conditions. For this contribution it was used to asses the influence of internal stack temperature for various reformates compositions as fuel that can not be measured directly in the experimental setup.

B1117

Technical Issues of Direct Internal Reforming SOFC (DIRSOFC) operated by Biofuels

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Abstract

Feasibility of a direct internal reforming SOFC (DIRSOFC) running on low-grade biofuels such as biogas and biodiesel fuels has been demonstrated in the previous research using anode-supported button cells. However, in the real SOFC system, the area near the fuel inlet is cooled down due to the strong endothermicity of reforming reactions (dry and steam reforming reactions of hydrocarbons), whereas cell temperature is gradually elevated toward the gas outlet by the exothermic electrochemical reactions. The strong temperature gradient along gas flow direction can cause cell fracture, and moreover it is thermodynamically expected that the carbon deposition and the impurity poisoning would be more significant at the cooled area.
In this study, these technical issues related to DIR operation of SOFC are discussed based on the electrochemical measurements of SOFCs operated with the direct feeding of biogas.

B1118

Steam Reforming of Methane using Ni-based Monolith Catalyst in Solid Oxide Fuel Cell System

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Abstract

Natural gas is a suitable fuel supply for solid oxide fuel cell (SOFC) system due to its increasingly improved infrastructure and relatively low cost. Natural gas should be reformed to syngas before it is introduced to SOFC system. Reforming catalyst is one of the key techniques in steaming reforming of natural gas. Compared with pellet catalyst, monolith catalyst can reduce the pressure drop and temperature gradient in the reformer. This work focuses on monolith catalyst and its usage in the reformer.
In this work, Ni-based monolith catalyst (modified by Mg) was prepared and tested in steam reforming of methane. When the water to methane ratio is 3, the conversion of methane reaches 99% at 800°C with the gas hourly space velocity (GHSV) is 3000 h^{-1}. Percentage of hydrogen in the reforming product gases is about 75% and the performance of this catalyst is stable. The interaction between Ni and support was analyzed using temperature-programmed reduction (TPR) technique and the results showed that NiO-MgO solid solution can strengthen the interaction between Ni and support so that the anti-carbon disposition ability and stability of the catalyst was improved.
Methane steam reformer testing equipment with the processing capability of 7 SLM CH_4 was established and it can meet the demand of 1~2 kW SOFC system. The hydrogen production of this reformer reaches 22.7 SLM and the conversion of CH_4 is 97.8%.

B1119

Modeling and experimental validation of SOFC operating on reformate fuel

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Abstract

With the prospect of running Solid-Oxide Fuel Cells (SOFCs) on multi-component mixtures, considerable attention is being directed to work SOFCs on diesel or gasoline reformates. This is an attractive option for the automobile industry due to the on-board availability of these fuels. These reformate fuels will essentially be a mixture of hydrocarbons and syngas. Depending on the conditions in the fuel reformer, CO_2/H_2O can also make up the constituents of the reformate fuel. Unlike SOFCs running on H_2 fuel, modeling those running on reformate fuels is a quite demanding task due to the coupled interactions of transport, heterogeneous chemistry and electrochemistry.

To the best of our knowledge, there exists no modeling work that validates the performance of a SOFC operating on a wide range of multi-component fuel mixtures with experimental measurements. A distributed charge transfer model is implemented to validate the system. The charge conservation equations used in the distributed charge transfer model are based on continuum conservation equations. Also, the utilization region is an outcome of the model prediction and validation is done for a range of fuel compositions.

This paper presents a fabric to model distributed charge transfer kinetics within the complete MEA structure combining charge transfer chemistry, catalytic chemistry, and porous media transport. Based on mean field approximation, the forward rate constants for heterogeneous chemical reactions are expressed in terms of a modified Arrhenius expression. The rate expression accounts for the surface coverage dependency of the chemical reaction on various surface adsorbed species. A heuristic approach is adopted for the evaluation of various model parameters. We present the modeling of experimental data reported by Tu et al., describing the performance of intermediate temperature SOFCs with catalytically processed methane fuels [1].

B1121

An Analysis of Heat and Mass Transfer in an Internal Indirect Fuel Reforming Type Solid Oxide Fuel Cell

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Abstract

The possibility of using indirect internal reforming is one of the advantages of high temperature fuel cells. Strong endothermic fuel reforming reactions can be thermally supported by the heat generated due to the sluggishness of electrochemical reactions, diffusion of participating chemical species and ionic and electric resistance. However, when operating at high temperatures, thermal management becomes an important issue. Typical Solid Oxide Fuel Cell reformer use Nickel as a catalyst material. Because of its prices and catalytic properties, Ni is used in both electrodes and internal reforming reactors. However, using Ni as a catalyst carries some disadvantages. Carbon formation is a major problem during a methane/steam reforming reaction based on Ni catalysis. Carbon formation occurs between nickel and metal-support, creating fibers which damage the catalytic property of the reactor. To prevent carbon deposition, the steam-to-carbon ratio is kept between 3 and 5 throughout the entire process. It was found that ceria-based catalyst materials are effective in suppression carbon deposition. This benefits the utilization of methane-rich fuels with a low steam-to carbon ratio. This paper presents three dimensional numerical studies on the fuel reforming process inside indirect internal reforming type solid oxide fuel cell using nickel supported on Samaria doped Ceria (SDC). Using presented model, the velocity field, concentration of the gases and temperature field was calculated due to discuss process in detail.

B1122

Experimental Study of a SOFC Burner/Reformer

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Abstract

Experimental and numerical analyses are performed for a self-designed non-premixed combustion after-burner/reformer of a solid oxide fuel cell system. The innovative after-burner/reformer is partitioned into four compartments: water evaporator, heat exchanger, reformer and porous media burner. The major functions of burner/reformer are to having a better mixture of gases, preheating anode and cathode gases, and providing thermal power for fuel reforming.

In this study, experiments at different operating temperatures and fuel compositions are executed to identify proper operating conditions for sufficient reforming efficiencies. When operated below a maximum temperature of 900 ^{o}C, a total concentration of hydrogen and carbon monoxide reaches to 80.43 % while flow rates of inlet air, methane and water are respectively 1.75 LPM, 2.1 LPM, and 3.05 cc/min. Additionally, numerical calculations are carried out to reveal the temperature distribution of the burner/reformer, especially in the region of porous media, so as to find suitable operating ranges. The calculated results are in good agreement with the measured data.

Keywords: SOFC; burner; reformer; non-premixed; combustion.

B1123

Double-Perovskite-Based Anode Materials for Solid Oxide Fuel Cells Fueled by Syngas

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Abstract

Nowadays it seems that the three main commercial applications of SOFCs, namely: Combined Heat and Power (CHP) units for households, Auxiliary Power Units (APU) for transportation and megawatt-class systems for central power generation (particularly for application in Integrated Gasification Fuel Cell (IGFC) systems), in order to be competitive, will require direct usage of hydrocarbon fuels (natural gas, syngas and others) instead of hydrogen. However, typical anode material, Ni-YSZ cermet, performs rather poorly while the cell is directly supplied with such fuels, which is related to sulfur poisoning and poor resistance to carbon deposition of Ni-YSZ. Therefore development of an effectively working anode material, which can be used with hydrocarbon fuels, is essential for the future progress of SOFC technology.
Already, there are literature reports showing attractive properties of several groups of possible novel anode materials, which may substitute Ni-YSZ. Analyzing the literature data, one may assume that the next step, which needs to be achieved for the successful anode material, is to develop a single-phase oxide with mixed ionic-electronic conductivity and high catalytic activity, which should fulfill all requirements for the application. Among possible candidates, materials having B-site double perovskite structure, belonging to $A_2MMoO_{6-\delta}$ (A: Sr, Ba; M: Mg, Mn, Fe, Co, Ni) group are of interest, due to their mixed ionic-electronic conductivity in reducing atmospheres, low values of thermal expansion coefficient, suitable catalytic properties and good chemical stability. Furthermore, they show relatively good tolerance for carbon deposition and can work in sulfur-containing atmospheres [1-8]. However, current understanding of the physicochemical properties of $A_2MMoO_{6-\delta}$ oxides is far from being complete.
In this work we show basic studies regarding crystal structure (XRD), transport properties (electrical conductivity σ, thermoelectric power α), thermogravimetric measurements including determination of oxygen diffusion coefficient D and surface exchange coefficient K of selected $Ba_{2-x}SrxNiMoO_{6-\delta}$ double perovskites, as well as the electrochemical properties (area specific resistance, cell's power density) of button-type, electrolyte-supported SOFC cells with $La_{0.8}Sr_{0.2}Co_{0.2}Fe_{0.8}O_{3-\delta}$ based cathode, $Ce_{0.8}Gd_{0.2}O_{1.9}$ electrolyte and $BaSrNiMoO_{6-\delta}$ based anode.

B1125

Synthesis of $LaAlO_3$ based electrocatalysts for methane-fueled solid oxide fuel cell anodes

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Abstract

Lanthanum aluminate based oxides, with perovskite-like structure, have displayed promising results for application as anode electrocatalysts for the oxidative coupling of methane in a solid oxide fuel cell (SOFC). This motivated the present work that reports the synthesis and characterization of intrinsic and doped $LaAlO_3$. Sr and Mn were individually doped in $LaAlO_3$ and also co-doped using the Pechini method. The substitution of La by Sr and/or of Al by Mn was used to enhance the material's electrical conductivity, catalytic activity and selectivity to C_2-hydrocarbons. The synthesis procedures were designed to produce electrocatalyst powders that fulfill requirements such as ease to be sintered, particle size control, high surface area, stoichiometric control of the reaction and morphology, well suited for the production of ceramic suspensions to be processed into an SOFC anode. The main results of chemical, thermal, dimensional, microstructural, morphological and electro-electronic characterizations have shown that the powders obtained present physical and chemical properties suitable for application as methane-fueled SOFC anodes, such as the matching of thermal expansion coefficient with those of the other components of the fuel cell, sufficient mixed ionic-electronic conductivity, resistance to coking and carbon clogging, as well as electrocatalytic activity for the partial oxidation of methane directly fed as a fuel to the SOFC.

B1201

SOFC Stack with Composite Interconnect

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Abstract

Solid Cell has developed a new patent-pending architecture for a planar single cell "compressed" into a Modified Planar Cell or MPC. YSZ is used as the solid electrolyte, and conventional electrode materials are used for anodes and cathodes. Three dimensional ceramic elements are net-shape manufactured by injection molding, a low cost mass production technology. Optimized electrodes for the MPC with high in-plane electric conductivity and a high rate of electrochemical reaction have been developed. The electrodes consist of multilayer porous structures of anode and cathode, which are impregnated by catalytic active nano-particles.

A critical component of the SOFC stack is the interconnect. Solid Cell has developed a new ceramic interconnect, which is a composite consisting of metallic nickel particles and titania doped by niobia particles. The CTE of the interconnect is matched to the CTE of YSZ by controlling the ratio of metallic and oxide phases in the interconnect material composition. The interconnect material has high mechanical strength. It is resistant to oxidation when exposed to hydrogen on one side and air on the other side, therefore maintaining high electronic conductivity for a very long time.

Although an MPC stack with a composite interconnect has moderate power density, it is compensated by several advantages: low cost of production, robustness, and durability. With the ceramic interconnect, an MPC-based SOFC is most suitable for kW class power range devices.

B1202

Recent Development in Pre-coating of Stainless Strips for Interconnects at Sandvik Materials Technology

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Abstract

In this presentation the current status of the development of pre-coated stainless steel strips for interconnects at AB Sandvik Materials Technology will be presented. The initial work have been focused on pre-coated materials for interconnects in SOFC by pre-coating Sandvik Sanergy HT with cobalt to eliminate chromium vapor release from the surface. Pre-coating of stainless steel strip can also be used to produce other interconnect/bipolar plates for other types of fuel cells. For instances carbon based coatings on 316L stainless steel have shown to be a very promising bipolar plate material for PEMFCs.

In the recent years, improvements of the cobalt layer have been realized by adding small amounts of cerium to the layer. The positive effect of cerium to reduce corrosion has been shown earlier [1] on FeCr model alloys. Further improvements of coatings will be presented and compared to earlier works.

In addition to coating specially designed alloys for SOFC applications, such as Sandvik Sanergy HT, work have been done to coat commodity ferritic grades such as ASTM 441.
Pre-coated ASTM 441 with Ce/Co shows equally good oxidation behaviors as well as contact resistance as Sandvik Sanergy HT. The main advantage to utilize commodity grades in combination with pre-coatings for the application as interconnect in SOFCs are a significant cost reduction per shaped interconnect plate.

1. S. Linderoth *et. al* Mat. Res. Soc. Symp. Proc. Vol 575, p 325, 2000

B1203

Corrosion behaviour of steel interconnects and coating materials in solid oxide electrolysis cell (SOEC)

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Abstract

High temperature steam electrolysis (HTSE), which is the electrolysis of steam at high temperature, offers a promising way to produce hydrogen with high efficiency. Compared with conventional water electrolysis, HTSE reduces the electrical energy requirement for the electrolysis and increases thermal efficiency of the power generating cycle. Among the various methods, SOEC (Solid Oxide Electrolysis Cell) has been considered one of the efficient ways. One efficient way of reducing the raw material and fabrication cost is to lower the operating temperature of the SOEC (from 1000°C to 600~700°C) thereby enabling the use of stainless steel interconnects. Stainless steel interconnects in the SOEC stack connect each cell in series by conducting electricity, distribute active gas to the cells and separate the hydrogen and oxygen between the cells. Although stainless steel interconnects can reduce the stack cost, they also introduce several challenges that hinder commercialization of the technology. Chromium oxide-forming alloys are preferred due to their high oxidation resistance associated with low electrical resistance, thus minimizing the ohmic loss within the stacks. However, chromium oxide scale can react with the anode materials and form non-catalytic and/or resistive compounds. These compounds finally lead to the degradation of the SOEC performance. In order to reduce the reaction between interconnect and anode electrode and to improve electrical contact as well, LNF($La(Ni_xFe_{1-x})O_3$), LSMC($(La_xSr_{1-x})(Mn_yCo_{1-y})O_3$) are proposed as a coating material between anode and interconnect. In this study, material compatibility between the proposed coating materials and the commercialized interconnects is investigated at SOEC operating temperature (700°C) with severe anode atmosphere (pure oxygen).
LNF and LSMC coated stainless steel interconnects (Crofer 22APU, K41X) are pre-heated at 750°C for 1.5h and subsequently heat treated for 200h and 3000h at 700°C with pure oxygen flow. LNF and LSMC layers (~60 μm) were deposited through screen-printing. In this configuration, especially for LNF/Crofer 22APU sample, Mn-Co oxide is additionally coated between LNF and Crofer 22APU as a protective coating material. The heat treated interconnect/coating samples are analysed using scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) mapping and line scanning. For selected samples, focused ion beam (FIB) and transmission electron microscopy (TEM) are used to investigate the corrosion mechanism of the stainless steel interconnect and the perovskite coating material.

B1204

Multifunctional nanocoatings on FeCr steels - influence on chromium volatilization and scale growth

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Abstract

Two important degradation mechanisms in Solid Oxide Fuel Cells (SOFCs) are directly related to the metallic interconnects. The formation of volatile chromium oxyhydroxides from metallic interconnects commonly causes fast degradation in cell performance due to poisoning of the cathode. Secondly high temperature corrosion of the metallic interconnect limits the lifetime of the stack eventually leading to the formation of non protective Fe rich oxide (so called break away corrosion). To reduce Cr volatilization 10-50µm thick ceramic coatings of perovskite or spinel type are commonly used. The current approach focuses on metallic Co coatings (that form a spinel during high temperature exposure) of sub µm thickness. This type of nano-coatings not only offers substantial cost reduction but also shows superior properties with respect to mechanical properties as well lower Cr volatilization. The latter has been evaluated with a recently developed denuder technique that allows direct and time resolved measurements of Cr evaporation.

In order to reduce high temperature corrosion of the interconnect 10nm thick layers of so called reactive elements (RE) like e.g. Ce, La, were applied. Despite its small thickness these layers substantially reduce the oxide growth rates and thus increase stack lifetime. The combination of a Co coating with an RE layer has also been investigated. The results show that the combined coating yields to a material with very low Cr evaporation in combination improved oxidation resistance.

The focus of this work is on a detailed understanding of the mechanisms and kinetics of the oxidation process of the substrate/coating system, which involves oxidation tests on the time scale from 15s to 3000h long-term tests.

B1205

Characterization of a Cobalt-Tungsten Interconnect Coating

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Abstract

A ferritic steel interconnect for a solid oxide fuel cell must be coated in order to prevent chromium evaporation from the steel substrate. The Technical University of Denmark and Topsoe Fuel Cell have developed an interconnect coating based on a cobalt-tungsten alloy. The purpose of the coating is to act both as a diffusion barrier for chromium and provide better protection against high temperature oxidation than a pure cobalt coating.

This work presents a characterization of a cobalt-tungsten alloy coating electrodeposited on the ferritic steel Crofer 22 H which subsequently was oxidized in air for 300 h at 800 °C. The coating was characterized with Glow Discharge Optical Spectroscopy (GDOES), Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD). The oxidation properties were evaluated by measuring weight change of coated samples of Crofer 22 H and Crofer 22 APU as a function of oxidation time.

The coating had completely oxidized during the 300 h oxidation time. GDOES measurements showed that the tungsten was located in an inner zone in the coating/substrate interface. The outer layer of the coating did not contain any tungsten after oxidation but consisted mainly of cobalt and oxygen with smaller amounts of iron and manganese. The iron and manganese had diffused from the steel into the coating during oxidation. XRD measurements showed that tungsten reacts with cobalt and oxygen to form $CoWO_4$. Cobalt oxide in the outer layer was a spinel of either Co_3O_4 or $Co_{3-y}(Mn,Fe)_yO_4$. Chromium in the steel had oxidized to form a thin layer of almost pure chromium oxide underneath the coating.

The coating appears to be an effective diffusion barrier for chromium as a very small amount of chromium was measured in the coating after oxidation. The cobalt-tungsten coated samples oxidized slightly slower than the cobalt coated samples.

An interconnect used in a fuel cell stack was also investigated with SEM/EDS. The interconnect from the fuel cell stack was different from the samples oxidized in the furnace with respect to the location of the tungsten. The tungsten in the interconnect coating was present in the chromium oxide layer instead of as $CoWo_4$ on top of it.

B1206

Barium-free sealing materials for high chromium containing alloys

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Abstract

The key-requirements for glass ceramic sealing materials to achieve high efficiencies in planar solid oxide fuel cells, are leak tightness, high insulating resistance, and low interfacial reactions in contact with the anode/cathode gases and the interconnect material.

Therefore SCHOTT has developed special glasses and glass-ceramics for chromium alloys, like Cr5FeY (CFY, Plansee), Especially the CFY material needs adapted sealing materials due to its high chromium content, which can easily form reaction products with the sealant, and its lower coefficient of thermal expansion (CTE) compared to ferritic stainless steels.

In this study, new glass-ceramic sealing materials for chromium containing alloys are presented. The glasses were casted to glass flakes and milled into powders of a mean grain size d_{50} of 10 ± 2 µm. Thermal analyses of the glass ceramics was conducted using dilatometry (TMA 500, Heraeus), hot-stage microscopy (Leitz) and differential scanning calorimetry (STA 449 F3 Jupiter, Netzsch). Interfacial reactions and bonding behavior towards the interconnect materials were studied using a scanning electron microscope (Gemini 1530, Zeiss) equipped with X-ray energy dispersive spectrometer (EDX, Noran). Leak tightness of sealed samples was studied using He-leakage tester (ASM 142, Alcatel).

Results show that barium-free glass-ceramics are advantageous when sealing high chromium alloys. Because of the absence of barium oxide, formation of detrimental chromate phases at the interface was avoided. The new glasses show low porosity, high hermeticity and strong bonding towards the CFY material, fulfilling the requirements of SOFC sealings.

B1208

Production of Pore-free Protective Coatings on Crofer Steel Interconnect via the use of an Electric Field during Sintering

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Abstract

In the present work, the production of pore-free coating in Crofer steel interconnect is reported at reduced temperatures with the application of an electric field during sintering process. In the experimental arrangement, the sample is sandwiched between a conducting electrode and the steel substrate and it is kept between two alumina plates which are also used for making contacts of Pt wires with the electrodes. Significant differences in the $MnCo_{1.9}Fe_{0.1}O_4$ coating microstructure can be observed after heat treatment with and without the application of the electric field (≈100 V/cm) and a voltage of 5 V. The present work deals with the development of an experimental frame of electrode/coating/substrate (other electrode) for applying electric field to get homogeneous consolidation profile all over the area of the coating. It also gives some preliminary hypotheses on the mechanism of particle sintering occurring in the coating during the heat treatment.

B1209

Metallic-ceramic composite materials as cathode/interconnect contact layers for solid oxide fuel cells

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Abstract

Power loss due to high contact resistance between metallic interconnect and ceramic cathode have been observed in solid oxide fuel cells (SOFCs). Further improvements in the cathode/interconnect contact can be achieved by combining two potential contact materials to form a composite. In the present work, composite contact materials were formed by a metallic mesh as high-temperature austenitic stainless steel and $LaNi_{0.6}Fe_{0.4}O_{3-\delta}$ (LNF) or $LaNi_{0.6}Co_{0.4}O_{3-\delta}$ (LNC) as conductive perovskites. In order to obtain an integrated system, the ceramic materials were placed onto the metallic mesh via tape casting technique.

Structural phase transitions by temperature, sintering behavior depending on particle size distribution and the electrical properties of the perovskites were evaluated against the requirements of the SOFC cathode/interconnect contact.

The stability and reactivity of perovskites with the metallic mesh and the adhesiveness between both materials was investigated by X-ray diffraction (XRD) and scanning electron microscopy (SEM) equipped with an energy dispersive X-ray analyzer (EDX). Chemical results show that composite materials are stable after they heated at 800 ºC for 300 h in air. Based on these results, it concludes that ceramic-metallic materials could be good candidates to use as cathode contact materials for SOFC.

B1210

The Oxidation of Selected Commercial FeCr alloys for Use as SOFC Interconnects

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Abstract

Ferritic stainless steel interconnectors are widely used due to their combination of low cost, compatible mechanical properties and conductive oxide scales. However, unsatisfactory high temperature corrosion resistance and chromium evaporation from the oxide surface are major obstacles to reaching lifetimes in the order of 40,000 operating hours

Chromium loss due to evaporation from the surface of a stainless steel interconnector contributes towards degradation of the interconnector material. In addition to this, the evaporated chromium poisons the cathode, significantly affecting stack lifetime

A number of ferritic interconnect materials are commercially available. Although similar, there are substantial variations in minor alloying elements. These variations could potentially have a significant impact on oxide scale properties and thus stack lifetime. This study compares and characterises the oxidation products and mechanisms for six commercially available interconnect materials with varying material constitutions: Crofer22 H, Crofer22 APU (ThyssenKrupp VDM), Sanergy HT (Sandvik Materials Technology), ZMG232 G10 (Hitachi), ATI 441 and E-brite (ATI metals).

Exposures are carried out in tubular furnaces at 850°C, with 6l/min airflow and 3% H_2O to simulate the air side atmosphere in a SOFC. Test durations range from 1 to 1000 hours. In addition to the oxidation tests, in-situ chromium evaporation measurements are carried out using a novel denuder technique.

The surface morphology and microstructure of the oxide scales are characterized using scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX).

B1211

A study of the oxidation behavior of selected FeCr alloys in environments relevant for SOEC applications

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Abstract

Solid Oxide Electrolysis Cell (SOEC) technology has gained increasing attention in recent years. It is a well-known fact that some renewable energies like e.g. wind or solar fluctuate substantially which can make grid load balancing more difficult. Indeed in countries like Denmark or Germany that have a high share of wind power production negative electricity prices have been observed. In order to balance these fluctuations the use of SOEC has attracted substantial interest due to the high power efficiency of SOEC units and their ability to produce both H_2 and CO.
The high degree of similarity between SOFC and SOEC technology has made it possible for SOEC development to achieve a substantial success in short time as much of the used know-how has been developed in the SOFC context earlier. The same is true for the choice of Interconnect materials for SOEC which relies basically on studies carried out in the SOFC context. However, although similar the suggested SOEC and SOFC atmospheres on the oxygen side vary substantially (oxygen partial pressure, humidity, flow rate, etc…) thus the current study investigates selected ferritic stainless steels under different SOEC cathode and anode conditions. It is expected that due to the high degree of optimization achieved in SOFC steel development a change in environment leads to different priorities regarding materials optimization. The study focuses on the two most important degradation phenomena related to the interconnect: corrosion and Cr volatility. Four different materials have been exposed in three environments: 1% O_2, 100% O_2 and 34% H_2O with 3% H_2 at 850°C. Chromium evaporation measurements have been carried out in the two oxygen containing environments. Chromium evaporation was found to vary largely with oxygen pressure, however the oxidation rates of the ferritic steels were similar in 100% O_2 and 1%O_2. Oxidation rate in 34% H_2O-5% H_2-Ar was generally lower than in dry oxygen atmospheres.

B1212

Thermo-Mechanical Fatigue Behavior of a Ferritic Stainless Steel for Solid Oxide Fuel Cell Interconnect

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Abstract

The purpose of this study is to investigate the thermo-mechanical fatigue behavior of a ferritic stainless steel (Crofer 22 H) for use as an interconnect material in planar solid oxide fuel cells (pSOFCs). Metallic interconnects are subjected to thermal stresses due to mismatch of coefficient of thermal expansion (CTE) between components and temperature gradients during start-up, steady operation, and shutdown stages in a pSOFC stack. Interconnects under mechanical and thermal cycling loading could suffer a thermo-mechanical fatigue (TMF) damage during operation between periodic start-up and shutdown stages. Therefore, TMF tests under various combinations of mechanical loading at a cyclic temperature range are conducted to study the long-term durability of the Crofer 22 H ferritic steel under SOFC operating conditions in the present study. The TMF tests were performed in air at a cyclic temperature range between 25°C and 800°C to simulate the maximum temperature range of pSOFCs between shutdown and steady operation stages. Cyclic mechanical loading was applied under force control with specified yield strength ratios (YSRs) at 25°C and 800°C to simulate various combinations of thermal stresses generated in interconnects of a pSOFC stack. Various combinations of YSRs ranging from 0.2 to 0.6 of at 25°C and 800°C were selected as the applied peak and valley mechanical loads at the temperatures of 25°C and 800°C in TMF tests. Experimental results show the TMF life of Crofer 22 H is mainly dominated by a fatigue mechanism involving cyclic plastic deformation. The relation between TMF life and YSR at 800°C for all given loading combinations is well described by a logarithmic function. Fractographic observation indicates a ductile fracture and fatigue cracking patterns in Crofer 22 H specimens. A fatigue mechanism involving cyclic plastic deformation is the dominant factor in determining the fracture mode of TMF behavior.

B1213

Reduction of Cathode Degradation from SOFC Metallic Interconnects by $MnCo_2O_4$ Spinel Protective Coating

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Abstract

One of the most important issues in the performance of SOFCs is the chromium poisoning of perovskite type materials used as cathode by the gaseous chromium species from metallic interconnects. A possible solution for this degradation can be a protective layer which act as an element migration barrier between the cathode and the metallic interconnect. Spinel protective coatings show excellent capability to prevent chromium poisoning of the fuel cell. In this study, Crofer 22 APU, SS430 and Conicro 4023 W 188, as metallic interconnect material, $La_{0.6}Sr_{0.4}FeO_3$ (LSF40) as cathode material and $MnCo_2O_4$, as spinel protective coating, were selected. The degradation studies between interconnect and cathode (LSF40) and the effectiveness of protective layer after oxidation at 800 ºC for 100 h in air, were studied by X-ray diffraction (XRD) and by field emission scanning electron microscopy (FEG) equipped with an Oxford Inca Pentafet X3 energy dispersive X-ray analyzer (EDX).
The application of spinel coating on metallic interconnects showed a significant reduction of Cr migration towards cathode and the improvement in electronic conductivity of the systems.

B1214

Dual-Layer Ceramic Interconnects for Anode-Supported Flat-Tubular Solid Oxide Fuel Cells

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Abstract

A flat-tubular solid oxide fuel cell (SOFC) combines all of the advantages of planar and tubular designs, such as an improved volumetric power density, a minimized sealing area and a high resistance to thermal cycling. In an anode-supported cell configuration, a thin interconnect layer is coated on one side of the porous anode support. It connects electrically unit cells and separates fuel from oxidant in the adjoining cells. In this paper, we report a dual-layer ceramic interconnect that is highly conductive and stable in both reducing and oxidizing atmospheres. The dual-layer interconnect consists of an *n*-type conducting $Sr_{0.7}La_{0.2}TiO_3$ layer on the anode side and a *p*-type conducing $La_{0.8}Sr_{0.2}MnO_3$ layer on the cathode side. Nano-sized powders are synthesized by the Pechini method using citric acid, and the materials properties such as electrical conductivities and thermal expansion coefficients are characterized. The interconnect is coated using the synthesized powder on a porous flat-tubular anode support by a screen printing process. The thin and dense dual-layer is obtained after co-sintering in air. The electrical characterization study shows that the dual-layer interconnect exhibits an area-specific resistance as low as 50 $m\Omega\ cm^2$ at 750°C when H_2/N_2 and air are supplied to the anode and cathode compartments, respectively. The performance of the anode-supported flat-tubular SOFC having the dual-layer interconnect is determined under various operating conditions.

B1215

Initial Oxidation of Ferritic Interconnect Steel - Effect due to a Thin Ceria Coating

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Abstract

Today there exist many ferritic stainless steel grades with a chemical composition specially designed to be used as interconnects in solid oxide fuel cell applications in a temperature interval of 650-850°C. The steels have good high temperature mechanical properties and corrosion resistance as well as good electron conductivity in the formed chromium oxide scale.

One way to substantially decrease the high temperature degradation of the interconnect steel i.e. improve properties such as increased surface conductivity and decreased oxidation and chromium evaporation is to coat the interconnect steel with suitable coatings. Today it is well known that a thin cobalt coating hinders chromium evaporation and a ceria coating lowers the oxidation rate at high temperature. Thus, by coating the interconnect steel the properties are improved to an extent that it should be possible to use a cheaper standard steel, e.g. AISI 441, as substrate for the coatings.

In this study the ferritic stainless steel alloys Sandvik Sanergy HT and AISI 441 is oxidized in laboratory air at temperatures at 750°C, 800°C and 850°C. The results show that a well adhered oxide scale of a complex layered structure is formed with significant amounts of Mn, Fe, Cr and Ti in the oxide scale. A Ce coating significantly reduces the growth rate of the oxide scale. The lower Cr content in the AISI 441 alloy does not affect the initial high temperature corrosion properties when coated with Ce. Also, the results demonstrate the usefulness of ToF-SIMS depth profiling for characterisation of the initial stages of oxidation of SOFC materials.

B1216

Fabrication of spinel coatings on SOFC metallic interconnects by electrophoretic deposition

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Abstract

Developing a protective coating for the metallic interconnects, which is electronically conductive, nonvolatile, and chemically compatible with other cell components, is one of the most straightforward and economical solution to prevent Cr migration and subsequent degradation. Fabrication of dense, conductive and protective layers by electrophoretic deposition (EPD) was the aim of the present research to suppress the release of Cr species by separating Cr_2O_3 from direct contact with the environment. $(Mn,Co)_3O_4$ spinel powders were used as starting materials. Non-aqueous suspension was prepared by adding spinel powder to organic medium, containing 0.25 $g.l^{-1}$ iodine as dispersant. The substrate material selected for coating experiments was AISI-SAE 430 stainless steel in the form of rectangular coupons (2X1X0.1 cm), which were polished to 600 grits using SiC sand paper and ultrasonically cleaned in acetone. The coupons were thoroughly coated in an electrophoretic cell. A parametric study was done over the effective parameters on EPD, including applied voltage, suspension concentration, and time. Optimized coating condition was chosen from the experiments to be 20 V, 10 $g.l^{-1}$, and 120 s, respectively. The effect of these parameters on the microstructure of EPD layers was also investigated from a kinetic point of view, to reach a more high-pack green coating. Afterwards, coated samples were sintered at 850 °C. High temperature oxidation behavior of bare and coated substrates was examined using a box furnace. The substrates were oxidized at 800 °C for 0 to 100 h. After exposures, the surfaces of the oxide scales and the cross sections of the substrates were investigated using a SEM/EDS and XRD. The electrical resistance of the coated samples was measured using a four-probe dc technique. The results showed that $(Cr,Mn)_3O_4$ has relatively high electrical conductivity and is a very stable phase.

B1217

Chromium evaporation from alumina and chromia forming alloys used in Solid oxide fuel cell-Balance of Plant applications

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Abstract

The evaporation, transport and re-deposition of chromium species from chromia forming alloys commonly used in interconnects and balance of plant (BOP) materials is one of the major cause for degradation in solid oxide fuel cell (SOFC) systems. A systematic study on the nature of scale, surface morphology and chemistry as well as chromium evaporation from select iron and nickel base alloys used in balance of plant (BOP) component materials is presented. The chromium evaporation was measured at SOFC operating tempartures using a transpiration method. The measured evaporation rates were correlated with oxide chemistry and morphology using microscopic observations of the various phase evolution in the oxide scales. In this work, we will compare Cr evaporation rates of chromia forming alloys and alumina forming alloys together with newly developed austenitic alumina forming (AFA) alloys from Oak Ridge National Laboratory. Also we will investigate the role of temperature and water vapor in Cr evaporation, scale formation.

B1218

High Performance Oxide Protective Coatings for SOFC Components

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Abstract

Chromia-forming ferritic stainless steels are a leading metallic interconnect candidate due to their protective chromia scale, thermal expansion compatibility with other stack components and low cost. The effective lifetime of these metallic interconnects is expected to be limited by oxidation-driven failure mechanisms. One strategy to achieve the required lifetime targets is to apply a protective coating such as manganese cobalt $(Mn,Co)_3O_4$ spinel, (MCO) to the stainless steel components.
NexTech Materials has systematically developed cost-effective approaches to synthesizing and depositing protective oxide coatings through value-conscious materials processing and deposition processes. Aerosol spray deposition (ASD) has been identified as a commercially-viable process, amenable to large scale manufacturing and capable of providing a low-cost coating solution.
To enable expeditious validation of the coating technology, high temperature testing protocols have been developed to accelerate oxidation kinetics and the corresponding failure mechanisms. Predictions for coated component lifetimes have been made based on relating oxidation kinetics with long-term electrical stability data.

B1301

Damage and Failure of Silver Based Ceramic/Metal Joints for SOFC Stacks

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Abstract

The increasing interest in lightweight solid oxide fuel cell (SOFC) systems for mobile applications has raised the awareness for questions concerning mechanical robustness of sealing materials in thermo-cyclic operation. In the planar SOFC design considered in the current work a metallic silver based braze sealant is used. Although, in contrast to brittle glass ceramics, these rather ductile metallic seals are considered to have advantages with respect to the reliability of the stack especially under thermal cycling conditions, the behavior of such sealant materials after application relevant thermal cyclic operation has not been reported so far. Hence, the post-operational characterization of a series of silver braze sealed stacks operated isothermally and under thermal cycling conditions is reported with particular emphasis on the braze morphology. The stacks were disassembled after operation, specimens were extracted in various characteristic positions, and metallographically prepared cross-sections were analyzed by optical and electron microscopy. It was observed that micro-pores were formed in the sealant that terminated stack operation, and that the extent of this porosity depended on the actual operation conditions leading eventually to leakage and in some cases even to melting effects. The discussion of the results focuses on the influence of different operation conditions on the damage progress and failure of silver based braze joints.

B1302

Development of barium aluminosilicate glass-ceramic sealants using a sol-gel route for SOFC application

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Abstract

One of the key problems in the fabrication of planar SOFCs is the sealing of the metallic interconnect to the ceramic electrolyte. The sealing material must be tight and stable in different atmospheres to insure a good separation between cathodic and anodic compartments and it must be chemically compatible with the other cell components. It is necessary that the sealing material resists to thermal stresses due to heating and cooling rate of a stack. Glass-ceramic sealants are great candidates to this application because of their high mechanical properties and the possibility to use a wide range of chemical compositions to control some physical properties like viscosity, coefficient of thermal expansion (CTE) and glass transition temperature.
In this work, the sealing materials studied are BXAS (BaO-X=B_2O_3, CaO, MgO-Al_2O_3-SiO_2) glass-ceramic. This kind of glass-ceramic is well known to exhibit good wetting behavior on both sealing surfaces (8YSZ electrolyte and stainless steel interconnect) and appropriate thermal properties. Glass-ceramic sealants are synthesized by using a non conventional process: the sol-gel route. This low cost process allows to obtain nanoscale homogeneity between cationic precursors in the mixture and to reduce the processing temperature for obtaining glasses. The raw materials used to prepare the oxide batches were respectively tetraethylorthosilicate, aluminum-tri-sec-butoxide and various acetate salts. Adequate heat treatments allowed the achievement of glass powders.
Measurements on as-formed glass expansion as a function of temperature were performed on glass pellets. Scanning electron microscopy technique was carried out to understand crystals' nucleation mechanisms and to explain variations of the CTE between different chemical compositions of the sealant material. Various techniques (DTA, hot stage microscopy) were used in order to determine optimal thermal treatment for sealing. Gas-tightness tests after sealing procedure and ageing treatment of 100 hours have been performed with steel-sealant-steel sandwiches. Joining degradation mechanisms were evaluated by microstructure investigation.
On the base of these results, almost all the glasses processed by sol-gel were identified as promising candidates for SOFC applications.

B1303

Strength Evaluation of Multilayer Glass-Ceramic Sealants

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Abstract

The glass-ceramic sealants developed at Forschungszentrum Juelich already meet several of the requirements for their potential use in solid oxide fuel cell (SOFC) stacks. The adequate choice of glass materials and adaptation of the joining and design parameters is essential for the assembling. For a successful long time operation of stacks, the strength of the bond must be sufficiently high as well. Nevertheless one of the major problems is to find a glass ceramic sealant with appropriate strength to withstand operation conditions. Therefore a reinforcement concept was developed. The reinforcement mechanism was based on the addition of several filler materials to a glass matrix of the system BaO-CaO-SiO_2. Silver particles and yttria-stabilized zirconia as fibres or particles were added as fillers. In addition, a layered structure of different composites was implemented in the joining gap to improve the bond strength to the interconnector. Each layer tailors a specific function and, in combination with the other layers, fulfils the overall requirements of the join. In a first attempt, different laminar combinations were screen-printed to yield a double and triple layer design. Steel plates of ferritic chromium-containing steel were chosen as joining partners. Two multiple layer design types of the joins were tested. The first type consists of two layers, one with ceramic filler and the other one with metal filler addition. The second type consists of three layers, which were set up by establishing two films of identical type on the outer sides to improve adhesion to the steel, and one reinforcement layer in the center plane. In order to analyse the influence of the multilayer design, tensile strength tests were carried out on circular butt-joint in comparison to single layered joins of the composite sealants. The combination of three layers showed best performance. Although the multilayer configurations could be qualitatively compared, the obtained results were used giving relative ranking, however no absolute values of strength. Consequently changes in the circular butt joint configuration were proposed to improve a quantitative evaluation of tensile strength.

B1304

SELF-HEALING SEALANTS AS A SOLUTION FOR IMPROVED THERMAL CYCLABILITY OF SOEC

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Abstract

The development of solid oxide fuel cells and high-temperature hydrolysers has led to the need for high temperature sealants, for which glass and glass-ceramics are among the most efficient solution. However, they suffer of cracking when subjected to thermal cycles. Self-healing is a promising solution to overcome this problem, for which two mechanisms exist: *intrinsic* and *extrinsic*. The intrinsic self-healing is based on the overheating of glass beyond its softening temperature, but it requires therefore external intervention. Conversely, the extrinsic self-healing is obtained by adding particles to the glass matrix, which will form a new glass upon contact with atmosphere in a crack, and thus it requires no external intervention. We will present our recent advances on self-healing glasses and glass-ceramics for SOEC sealants. Both intrinsic and extrinsic methods offer advantages and limitations that we will describe. We used original characterization tools like solid-state NMR and *In situ* high-temperature electron microscopy. Healing tests were conducted on small samples as well as on complete cells, and we observed that healing was effective upon thermal cycling. New original healing architecture will be presented, based on alternated layers of glass and healing compounds deposited by Pulsed laser Deposition.

B1305

Long term stability of glasses in SOFC

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Abstract

Ceramic Fuel Cells Limited (CFCL) has a 2 kWe Solid Oxide Fuel Cell (SOFC) product called BlueGen that operates 24/7/365 that converts 60% of the energy in natural gas to electricity and provides 25% additional energy as heat [1]. CFCL's stack design is based on ferritic steel interconnects and anode supported cells. The development of the stack has been described previously [2] and the performance consistency of the stack in a product and typical performance in commercial operating environments is described elsewhere [3].

Glass or glass-ceramic seals are a component of most planar SOFC stack designs and an integral part of CFCL stacks. The glass-ceramic seal is an important component in the mechanical robustness of the stack when the stack is sintered during manufacture and through the full lifetime of the product. As such the glass-ceramic characteristics are designed to meet high yields in stack manufacture and to meet the demands of repeated thermal and mechanical stresses on start up, operation, and shut down, and to do so after many years of continuous exposure to fuel gas and air at operating temperatures.

This paper shows results of three glasses that have been studied for long term ageing in air at stack operating temperatures 700 - 800 °C. It was observed that the crystal size, crystal content and porosity can grow with time. The results show that the ageing process can be slowed significantly and along with the BlueGen power cycling and thermal cycling results that are also shown in this paper gives good confidence in BlueGen as an SOFC product for commercial applications. BlueGen however remains a new product and product operation has so far been to over 15,000 hours since CE approval in April 2010 and the observed trends in crystal growth and porosity indicate that the glass ceramic seal could continue to change for periods beyond one year. As such this paper focuses on the material characteristics of glass-ceramic seals that are an integral component in the robustness of SOFC stacks and the nature of long term behavior to provide insight to how the glass-ceramic seal will behave after one year of product operation.
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B1306

Impact of thermal cycling in dual-atmosphere conditions on the microstructural stability of reactive air brazed metal/ceramic joints

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Abstract

In the field of SOFC development different testing methods are established to gather mechanical properties of the utilized materials. All these testing methods are aimed towards realistic mechanical stresses and strains that arise during SOFC operation, like shear-, tensile- or bending loads. Thermochemical reactions within the sealing material, facing both oxidizing and reducing atmosphere conditions, as well as possible interaction of thermochemical and thermomechanical degradation processes in isothermal or thermal cycling operation are not yet considered in the established mechanical testing schedules. Post-test analysis of SOFC-stacks frequently reveal void and pore formation within metallic sealing materials. In some cases the state of porosity is that pronounced that mechanical failure may be the consequence in prolonged cyclic operation.

This paper concentrates on the development of a novel method that enables "close to reality" testing of metal/ceramic joints in dual-atmosphere conditions. Tests under isothermal as well as thermal cycling conditions were carried out to investigate the thermomechanical and thermochemical influence on the microstructural stability of metallic sealing materials. Finally results of the testing campaigns in dual atmosphere conditions are presented and discussed.

B1307

THE ELECTRICAL STABILITY OF GLASS CERAMIC SEALANT IN SOFC STACK ENVIRONMENT

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Abstract

The electrical stability of a commercially available G018-354 glass ceramics is investigated in a real stack environment under wide range of conditions. The effects of the seal thickness, operation temperature and interconnect coating on the electrical resistivity are examined at various operational current densities. It was found that the electrical resistivity of the glass ceramics decreases with the increasing current densities and temperature. The coating of the interconnector with Al_2O_3 which is employed for protection of chromium evaporation is found to have an adverse effect on the glass ceramic resistivity. It is found that at least 0.3mm thick glass ceramic sealant is required to avoid short circuit.

B1308

Lanthanum Chromite - Glass Composite Interconnects for Solid Oxide Fuel Cells

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Abstract

In order to improve the sintering ability and electrical conductivity of La0.8Ca0.2CrO3 (LCC), LCC/glass composite interconnect materials for high temperature solid oxide fuel cells (SOFCs) were studied in this paper. Glass is known as a sintering aid for improving sintering ability. It promotes liquid phase sintering and improves densification during the sintering process. The components of the glass used in this study are B2O3, SrO, La2O3, SiO2 and Al2O3.The phase stability, microstructure, electrical conductivity and thermal expansion coefficient (TEC) were measured to determine the optimal glass content in the composite materials. All of the tested composite materials showed perovskite structures and dense microstructures. It was found that the addition of up to 5 wt.% glass increased the sintering ability and the electrical conductivity in both air and hydrogen atmospheres. The glass powder enhances the sintering behavior because it acts as a liquid phase sintering aid and the Sr2+ ion in glass powder generates $[Sr'_{La}]$ and $[Cr^{\bullet}_{Cr}]$. These lead to improvement in the electrical conductivity of the material. The TEC of the composites indicated compatibility with other cell components. The above results present that LCC/glass composite materials are suitable to be used as interconnects for SOFCs.

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B1309

High-Temperature Joint Strength and Durability Between a Metallic Interconnect and Glass-Ceramic Sealant in Solid Oxide Fuel Cells

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Abstract

The joint strength between a newly developed solid oxide fuel cell glass-ceramic sealant (GC-9) and an interconnect steel (Crofer 22 H) coated with $La_{0.67}Sr_{0.33}MnO_3$ (LSM) was investigated at 800 °C and compared with that without LSM coating. In addition, creep rupture properties of the joint specimens without LSM coating were also investigated at 800 °C under constant shear and tensile loading. Both the shear and tensile bonding strengths at 800 °C of the joint specimens coated with LSM were less than those of the non-coated ones. Analysis of interfacial microstructure indicated presence of microvoids and microcracks at the $BaCrO_4$ chromate layer on glass-ceramic sealant. When the LSM coating on the metallic interconnect and $BaCrO_4$ layer on the glass-ceramic sealant were joined together with incompatible deformation, microvoids/microcracks were formed at the $BaCrO_4$ layer. In this regard, the joint strength was degraded by such a coating. The creep rupture time of both shear and tensile joint specimens was increased with a decrease in the applied constant load at 800 °C. The creep joint strength at 1000 h under shear loading was about one fifth of the ultimate shear joint strength at 800 °C. The tensile creep joint strength at 1000 h was about 8% of the ultimate tensile joint strength at 800 °C. The failure pattern of the shear joint specimens with a shorter creep rupture time was similar to that subject to a monotonic loading in the shear joint strength test while a different failure pattern was found for a longer creep rupture time. For the tensile joint specimens in creep test, fracture always took place at the interface between the glass-ceramic substrate and $BaCrO_4$ layer.

B1310

Characterization of the mechanical properties of solid oxide fuel cell sealing materials

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Abstract

A promising candidate to fulfil the requirements of gas tightness, high temperature stability and electrical insulation appear to be glass-ceramic sealing materials. However, the reliable operation of solid oxide fuel cell stacks depends strongly on the structural integrity of the sealing materials. In this respect failure and deformation are aspects which need to be assessed in particular for glass ceramic sealant materials. Bending tests were carried at room temperature and typical stack operation temperature for glass ceramic sealants with different degree of crystallization. Elastic moduli, fracture stresses and viscosity values are reported. In addition to sintered bars bending testing were carried out for steel specimens that were head-to-head joined with the glass ceramics similar as in a stack application. The ceramic particle reinforced sealant material was screen printed onto the steel. The results reveal a decrease of the strength for the partially crystallized sealant at operation relevant temperatures that can be associated with the viscous deformation of the material. Fractographic analyses based on a combination of optical, confocal and scanning electron microscopy gives insight into the failure origin.

B1311

A Calcium-Strontium Silicate Glass for Sealing Solid Oxide Fuel Cells: Synthesis and its interfacial reaction with stack parts

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Abstract

Fabrication of a proper glass seal to prevent gas mixture and maintain electrical isolation is one of the most important challenges for developing IT-SOFC's. In the present study, a glass containing SiO_2-B_2O_3-SrO-CaO-Al_2O_3-La_2O_3 was investigated as a candidate sealing glass for SOFC applications. The thoroughly mixed batches were melted in an electric furnace at 1400 °C for 1 h. The melts were quenched by pouring into distilled water, dried and then milled in a planetary ball-mill for several minutes, resulting in fine glass powders with 10-12 µm in average particle size. The thermal properties of the glass powders, such as transition temperature (T_g=670 °C), softening point (T_s=720 °C) and crystallization temperatures (T_c) were determined in air using a differential thermal analyzer (DTA). From variation of DTA peaks with heating rate, the activation energy for glass crystallization was calculated to be 420 kJ/mol using a kinetic model. The major crystalline phases formed on thermal treatments of the glass were identified by powder X-ray diffraction, including strontium aluminum silicate, anorthite, and calcium lanthanum silicate. The interfacial compatibility of the glass tapes with AISI 430 interconnects and YSZ electrolyte was investigated at 800 °C for 100 h in air. For this aim, glass tapes were fabricated from organic-based tape-cast 80 µm sheets, were then laminated to the final thickness of 300 µm. The glass tape was sandwiched between metallic plate and sintered YSZ tape. The sintering and joining were carried out by heating in air to 850 °C for 1 h, followed by a dwell at 800 °C for maximum 100 h. Microstructural studies, with scanning electron microscopy and energy dispersive spectroscopy, revealed that the glass is compatible with adjacent parts, with no deterioration in the interface. High temperature leakage test was performed using a self-constructed system. In a simulated condition of SOFC operation, the glass succeeded to be gas-tight in a 100h long test.

B1312

Optimizing Sealing in Solid Oxide Fuel Cell Systems with Compressible Gaskets

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Abstract

This paper examines the critical factors when considering compressible seals in solid oxide fuel cell systems. Tests were conducted using a benchmark compressible gasket, the results of which show the impact on sealing effectiveness of material creep, organic content of the gasket, its dielectric strength, and available bolt load. This paper focuses on these and other issues crucial to the successful utilization of such seals in SOFC applications.

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Topsoe Fuel Cell A/S,
Lyngby/Denmark

TU Bergakademie Freiberg, Institute of Thermal Engineering
Freiberg/Germany

U.S. DOE National Energy Technology Laboratory
Morgantown/USA-WV

UJF-Grenoble1, INP/CNRS
Grenoble/France

United Technologies Research Center (China), Ltd.
Shanghai/China

Univ. de Bordeaux
Bordeaux/France

Universidad Autónoma de Nuevo León, Facultad de Ingeniería Mecánica y Eléctrica
México/México

Universidad del País Vasco UPV/EHU, Departamento de Química Inorgánica
Bilbao/Spain

Universidad del País Vasco/Euskal Herriko Unibertsitatea (UPV/EHU)., Facultad de Ciencia y Tecnología
Leioa (Vizcaya)/Spain

Universidad Politécnica de Valencia, Instituto de Tecnología Química
Valencia/Spain

Université du Maine, Institut de Recherche en Ingénierie Moléculaire et Matériaux Fonctionnels, CNRS, Laboratoire des Oxydes et Fluorures
/France

Université Lille Nord de France, Unité de Catalyse et Chimie du Solide
Villeneuve d'Ascq/France

Université Pierre et Marie Curie, LCMCP, Laboratoire Chimie de la Matière Condensée de Paris
Paris/France

University College London
London/UK

University of Alberta, Department of Chemical & Materials Engineering
Edmonton/Canada

University of Applied Science Western Switzerland, Design and Materials Unit
Sion/Switzerland

University of Applied Sciences Giessen
Giessen/Germany

University of Bergen, Institute for Physics and Technology
Bergen/Norway

University of Bologna, Department of Industrial Chemistry and Materials (INSTM)
Bologna/Italy

University of California, Center for Energy Research, San Diego
La Jolla/USA-CA

University of Connecticut, Center for Clean Energy Engineering, and Department of Chemical, Materials & Biomolecular Engineering
Storrs/USA-CT

University of Erlangen-Nuremberg, Chair for Energy Process Engineering
Nuremberg/Germany

University of Houston, College of Technology
Houston/USA-TX

University of Patras, Department of Chemical Engineering
Patras/Greece

University of Perugia, FCLAB
Perugia/Italy

University of Pisa, Department of Chemical Engineering
Pisa/Italy

University of São Paulo, Nuclear and Energy Research Institute
São Paulo/Brazil

University of Science and Technology, Department of Advanced Energy Technology
Daejeon/South Korea

University of St Andrews, School of Chemistry
St Andrews/UK

University of Tokyo, Institute of Industrial Science
Tokyo/Japan

University of Trento
Trento/Italy

Versa Power Systems
Calgary AB/Canada

Vestel Defense Industry
Ankara/Turkey

VTT, Technical Research Centre of Finland
Espoo/Finnland

Warsaw University of Technology, Institute of Heat Engineering
Warsaw/Poland

Wärtsilä, Fuel Cells
Espoo/Finland

Yonsei University, Department of Materials Science and Engineering
Seoul/South Korea

Zahner-Elektrik GmbH & Co. KG
Kronach/Germany

ZBT GmbH
Duisburg/Germany

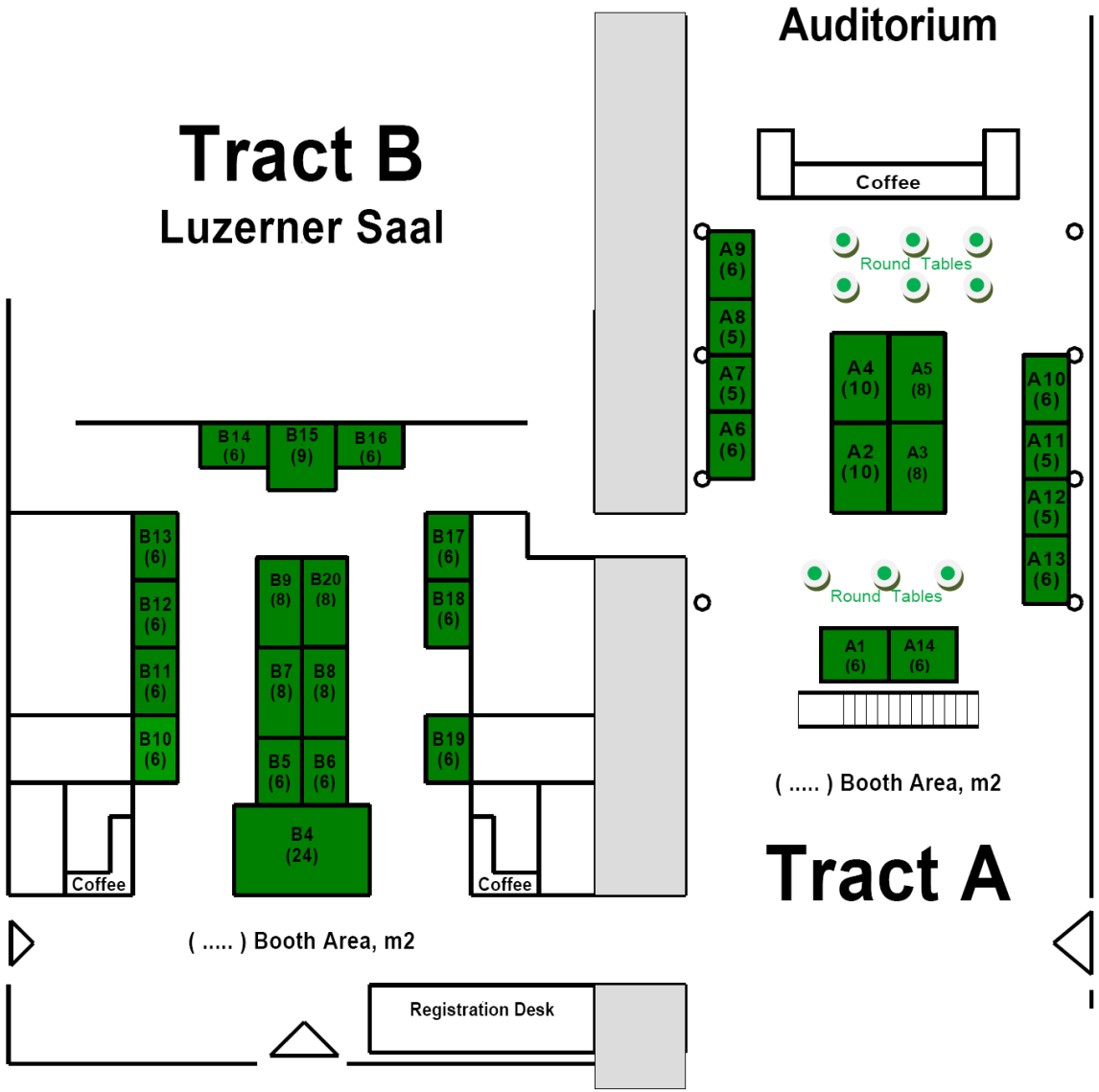
Zurich University of Applied Sciences (ZHAW), Institute for Computational Physics
Winterthur/Switzerland

List of Exhibitors

Registered by 13th of June 2012

10th EUROPEAN SOFC FORUM 2012

26 - 29 June 2012 KKL Lucerne / Switzerland



Booth B18

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List of Booths 10th EUROPEAN SOFC FORUM 2012

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Both	Exhibitor	Country	Contact
A02	H.C.Starck Ceramics GmbH	Germany	Ms Sandra Blechschmidt
A04	CEA LITEN	France	Mr Nicolas Bardi
A06	KNF Flodos AG	Switzerland	Mr Jean Delteil
A07	FLEXITALLIC	United Kingdom	Mr John Hoyes
A08	Fiaxell Sàrl	Switzerland	Mr Raphael Ihringer
A09	Treibacher Industrie AG	Austria	Ms Gudrun Leitgeb
A10	Deutsches Zentrum für Luft- und Raumfahrt DLR e.V.	Germany	Ms Sabine Winterfeld
A11	INRAG AG	Switzerland	Mr Uwe Scherner
A12	fuelcellmaterials.com	USA	Ms Michelle Trolio
A13	HAYNES International Nickel-Contor AG	Switzerland	Mr Felix Handermann
B04	Forschungszentrum Juelich GmbH	Germany	Dr. Manfred Wilms
B05	eZelleron GmbH	Germany	Ms Jenny Richter
B06	Bronkhorst (Schweiz) AG	Switzerland	Ms Chantal Gschwind
B07	EBZ GmbH	Germany	Ms Eva Spickenheuer
B08	CerPoTech AS	Norway	Ms Ruth Astrid Strom
B09	ESL Europe	United Kingdom	Mr Ernst Eisermann
B09	HTceramix SA	Switzerland	Mr Olivier Bucheli
B09	SOFCpower SpA	Italy	Mr Olivier Bucheli
B10	KERAFOL GmbH	Germany	Ms Rilana Weissel
B11	Staxera	Germany	Mr Björn Erik Mai
B12	Fraunhofer IKTS	Germany	Ms Katrin Schwarz
B13	Plansee SE	Austria	Ms Brigitte Plangger
B14	FuelCon AG	Germany	Ms Andrea Bartels
B15	HERAEUS PRECIOUS METALS GmbH & Co. KG	Germany	Ms Anette Kolb
B17	Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences, Division of Fuel Cell and Energy Technology	P.R. China	Ms Yi Zhang
B18	AVL List GmbH	Austria	Mr Jürgen Rechberger
B19	Hexis AG	Switzerland	Mr Volker Nerlich
B20	Elcogen AS	Estland	Mr André Koit

Outlook 2013

In this moment of preparation, we are excited to see all the valuable contributions and efforts of so many authors, scientific committee and advisors, exhibitors and staff materialising in the EUROPEAN SOFC & SOE FORUM 2012. However, looking a little bit beyond these intensive days, we see another important event emerging at a not too far horizon in 2013:

The 4th European PEFC and H_2 Forum

Science, Technology and Application of Low Temperature Fuel Cells and Hydrogen

The 4th EUROPEAN PEFC and H_2 FORUM will be a major European gathering place for low temperature fuel cell and hydrogen scientists, experts and engineers, but also increasingly business developers and managers. Responding to the wishes of many stakeholders, the event will be exclusively focussing on all low temperature fuel cell, electrolyser and hydrogen technologies.

Already now, many people have expressed their strong interest to participate and contribute to this event as scientists, engineers or exhibitors. All kind of low temperature fuel cells as well as hydrogen production, storage and distribution technologies will be presented to the public. On the one hand, the technical focus lies on specific engineering and design approaches and solutions for materials, processes and components. On the other hand, increasingly broad demonstration projects and first in series produced applications and products are presented.

The forum comprises a scientific conference, an exhibition and a tutorial. The Scientific Conference will address issues of science, engineering, materials, systems and applications as well as markets for all types of low temperature Fuel Cells and Electrolysers. In its traditional manner, the meeting aims at a fruitful dialogue between researchers, engineers and manufacturers, hardware developers and users, academia and industry. Business opportunities will be identified for manufacturers, commerce, consultants, public authorities and investors. Although a Europe-bound event, participation is invited from all continents. About 500 participants and 30 exhibitors are expected from more than 30 nations.

For 2013, the EFCF's International Board of Advisors has **elected**

Prof. Dr. Deborah Jones as **Chairwoman**

of the next conference. She is Director of Research at CNRS and heads the laboratory for "Aggregates, Interfaces and Materials for Energy" at the Institute for Molecular Chemistry and Materials at Montpellier University, France. She has been working in the field of the development of membrane materials for proton exchange membrane fuel cells since the mid 1990's and initiated the international conference series on Progress in materials for medium and high temperature polymer electrolyte fuel cells.
A Scientific Advisory Committee has been formed to structure the technical programme in an independent and neutral manner and will exercise full scientific independence in all technical matters.

For everybody interested in low temperature Fuel Cells and Hydrogen, please take note in your agenda of the next opportunity to enjoy Lucerne as scientific and technical exchange platform. The 4th EUROPEAN PEFC & H2 FORUM will take place from
2 to 5 July 2013, in Lucerne, Switzerland.

We look forward to welcoming you again in Lucerne.

The organisers Olivier Bucheli & Michael Spirig

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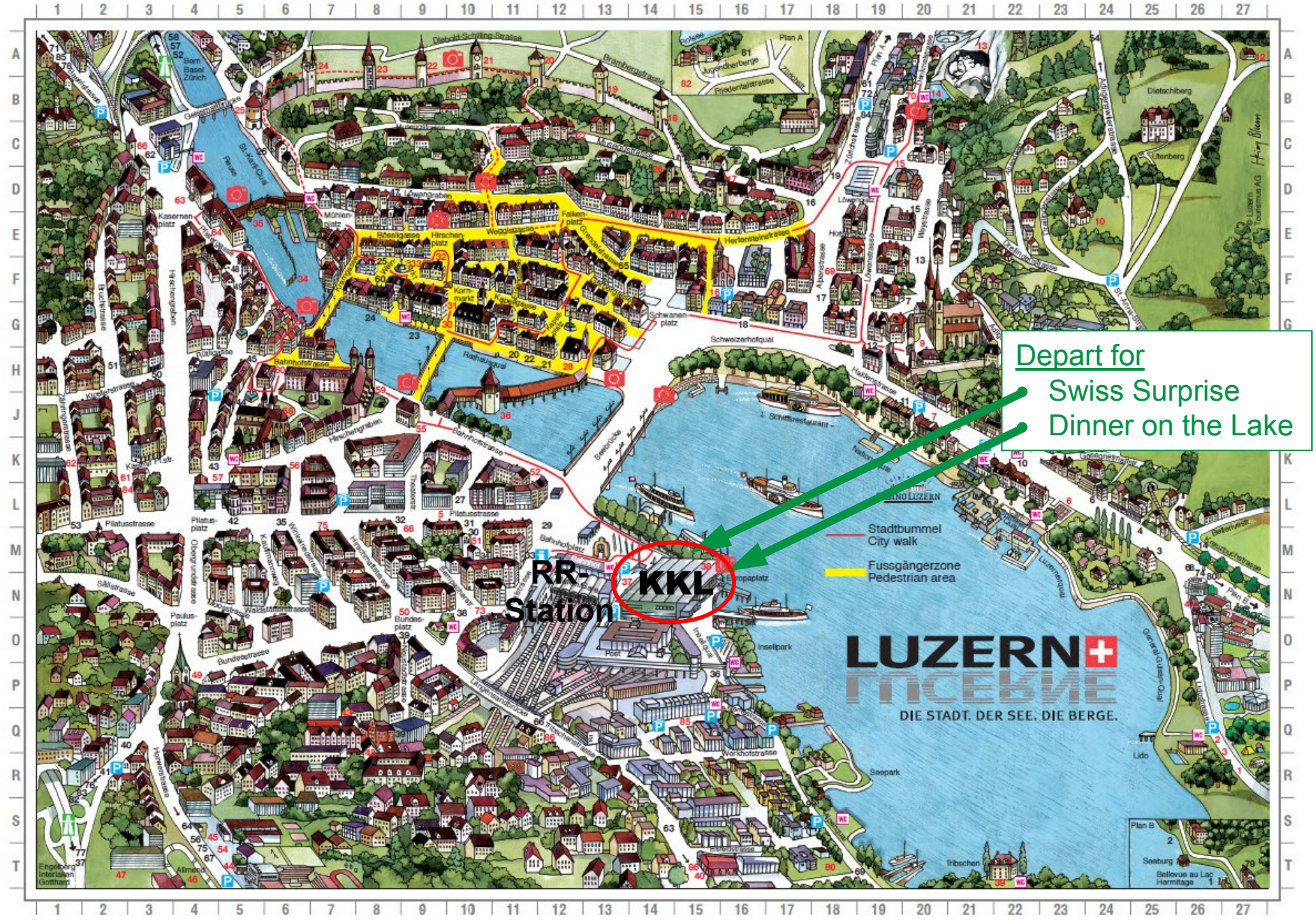
Depart for
Swiss Surprise
Dinner on the Lake
RR-Station
KKL
Stadtbummel
City walk
Fussgängerzone
Pedestrian area
LUZERN
DIE STADT. DER SEE. DIE BERGE.

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International conference on SOLID OXIDE FUELL CELL and ELECTROLYSER

10th EUROPEAN SOFC FORUM 2012

26 - 29 June 2012

Kultur- und Kongresszentrum Luzern (KKL) Lucerne / Switzerland

Schedule of Events

Tuesday – 26 June 2012	10:00 - 16:00	Exhibition set-up
	10:00 - 16:00	**Tutorial** by Dr. Günther Scherer & Dr. Jan Van herle
	14:00 - 18:00	Poster pin-up
	16:00	Official **opening of the exhibition**
	16:00 - 18:00	Registration (continued on following days)
	18:00 - 19:00	**Welcome gathering** on terrace above registration area
	from 19:00	**Thank-You Dinner** according to special invitation and Networking meetings (in individual groups)
Wednesday – 27 June 2012	08:00 - 09:00	Speakers Breakfast (World Café at ground floor KKL)
	09:00 - 18:00	Conference **Sessions 1-5** including keynotes on international overview from Europe, China, Japan, Korea and USA, **Poster presentation** by authors, networking and exhibition
	12:30	Press Conference (by invitation only)
	18:30 - 23:00	**Swiss Surprise Event** (optional, separate registration)
Thursday – 28 June 2012	08:00 - 09:00	Speakers Breakfast (World Café at ground floor KKL)
	09:00 - 18:00	Conference **Sessions 6-10** including technical keynotes on advanced characterisation and diagnosis **Poster presentation** by authors, networking and exhibition
	09:00 - 18:00	Access to poster area
	19:30 - 23:00	**Great Dinner on the Lake**
Friday – 29 June 2012	08:00 - 09:00	Speakers Breakfast (World Café at ground floor KKL)
	09:00 - 16:00	Conference **Sessions 11-15** including keynotes on SOFC for Distributed Power Generation, networking and exhibition
	09:00 - 12:00	Access to **poster** area
	12:00 - 14:00	Poster removal
	16:00 - 17:00	**Award & Closing** Ceremony – Christian Friedrich Schönbein & Hermann Göhr Awards

Motto 2012: **New perspectives opened by Solid Oxide technologies: International Programs, Research and Realizations, Market Entry.**