

# High Temperature Solid Oxide Fuel Cells

Fundamentals, Design  
and Applications



Subhash C Singhal and Kevin Kendall

# Hightemperature Solid Oxide Fuel Cells Fundamentals Design And Applicatons

**Detlef Stolten, Bernd Emonts**



## **Hightemperature Solid Oxide Fuel Cells Fundamentals Design And Applicatons:**

### **High-temperature Solid Oxide Fuel Cells: Fundamentals, Design and Applications** S.C. Singhal,K.

Kendall,2003-12-08 High Temperature Solid Oxide Fuel Cells Fundamentals Design and Applications provides a comprehensive discussion of solid oxide fuel cells SOFCs SOFCs are the most efficient devices for the electrochemical conversion of chemical energy of hydrocarbon fuels into electricity and have been gaining increasing attention for clean and efficient distributed power generation The book explains the operating principle cell component materials cell and stack designs and fabrication processes cell and stack performance and applications of SOFCs Individual chapters are written by internationally renowned authors in their respective fields and the text is supplemented by a large number of references for further information The book is primarily intended for use by researchers engineers and other technical people working in the field of SOFCs Even though the technology is advancing at a very rapid pace the information contained in most of the chapters is fundamental enough for the book to be useful even as a text for SOFC technology at the graduate level

### **High-temperature Solid Oxide Fuel Cells: Fundamentals, Design and Applications** S.C. Singhal,K.

Kendall,2003-12-08 Introduction History of SOFCs Thermodynamics Electrolyte Cathode Anode Interconnect ceramic metallic Electrode Polarizations Fuels and Fuel Processing Cell and Stack Designs Cell and Stack Modelling Cell and Stack Testing Applications and Demonstrations High-Temperature Solid Oxide Fuel Cells for the 21st Century Kevin Kendall,Michaela Kendall,2015-11-21 High temperature Solid Oxide Fuel Cells Second Edition explores the growing interest in fuel cells as a sustainable source of energy The text brings the topic of green energy front and center illustrating the need for new books that provide comprehensive and practical information on specific types of fuel cells and their applications This landmark volume on solid oxide fuel cells contains contributions from experts of international repute and provides a single source of the latest knowledge on this topic A single source for all the latest information on solid oxide fuel cells and their applications Illustrates the need for new more comprehensive books and study on the topic Explores the growing interest in fuel cells as viable sustainable sources of energy *Solid Oxide Fuel Cells* Jeffrey Fergus,Rob Hui,Xianguo Li,David P. Wilkinson, Jiujun Zhang,2016-04-19 The First Book Centered on Materials Issues of SOFCs Although the high operating temperature of solid oxide fuel cells SOFCs creates opportunities for using a variety of fuels including low grade hydrogen and those derived from biomass it also produces difficulties in materials performance and often leads to materials degradation during operatio *Advances in Medium and High Temperature Solid Oxide Fuel Cell Technology* Marta Boaro,Aricò Antonino Salvatore,2016-11-24 In this book well known experts highlight cutting edge research priorities and discuss the state of the art in the field of solid oxide fuel cells giving an update on specific subjects such as protonic conductors interconnects electrocatalytic and catalytic processes and modelling approaches Fundamentals and advances in this field are illustrated to help young researchers address issues in the characterization of materials and in the analysis of

processes not often tackled in scholarly books      **Solid Oxide Fuel Cells** Bin Zhu, Rizwan Raza, Liangdong Fan, Chunwen Sun, 2020-06-02 Presents innovative approaches towards affordable highly efficient and reliable sustainable energy systems Written by leading experts on the subject this book provides not only a basic introduction and understanding of conventional fuel cell principle but also an updated view of the most recent developments in this field It focuses on the new energy conversion technologies based on both electrolyte and electrolyte free fuel cells from advanced novel ceria based composite electrolyte low temperature solid oxide fuel cells to non electrolyte fuel cells as advanced fuel to electricity conversion technology Solid Oxide Fuel Cells From Electrolyte Based to Electrolyte Free Devices is divided into three parts Part I covers the latest developments of anode electrolyte and cathode materials as well as the SOFC technologies Part II discusses the non electrolyte or semiconductor based membrane fuel cells Part III focuses on engineering efforts on materials technology devices and stack developments and looks at various applications and new opportunities of SOFC using both the electrolyte and non electrolyte principles including integrated fuel cell systems with electrolysis solar energy and more Offers knowledge on how to realize highly efficient fuel cells with novel device structures Shows the opportunity to transform the future fuel cell markets and the possibility to commercialize fuel cells in an extended range of applications Presents a unique collection of contributions on the development of solid oxide fuel cells from electrolyte based to non electrolyte based technology Provides a more comprehensive understanding of the advances in fuel cells and bridges the knowledge from traditional SOFC to the new concept Allows readers to track the development from the conventional SOFC to the non electrolyte or single component fuel cell Solid Oxide Fuel Cells From Electrolyte Based to Electrolyte Free Devices will serve as an important reference work to students scientists engineers researchers and technology developers in the fuel cell field

Intermediate Temperature Solid Oxide Fuel Cells Gurbinder Kaur, 2019-11-21 Intermediate Temperature Solid Oxide Fuel Cells Electrolytes Electrodes and Interconnects introduces the fundamental principles of intermediate solid oxide fuel cells technology It provides the reader with a broad understanding and practical knowledge of the electrodes pyrochlore perovskite oxide electrolytes and interconnects which form the backbone of the Solid Oxide Fuel Cell SOFC unit Opening with an introduction to the thermodynamics physiochemical and electrochemical behavior of Solid Oxide Fuel Cells SOFC the book also discusses specific materials including low temperature brownmillerites and aurivillius electrolytes as well as pyrochlore interconnects This book analyzes the basic concepts providing cutting edge information for both researchers and students It is a complete reference for Intermediate Solid Oxide Fuel Cells technology that will be a vital resource for those working in materials science fuel cells and solid state chemistry Provides a single source of information on glass electrolytes interconnects vanadates pyrochlores and perovskite SOFC Includes illustrations that provide a clear visual explanation of concepts being discussed Progresses from a discussion of basic concepts that will enable readers to easily comprehend the subject matter      *Perovskite Oxide for Solid Oxide Fuel Cells* Tatsumi Ishihara, 2009-06-12 Fuel cell technology is quite

promising for conversion of chemical energy of hydrocarbon fuels into electricity without forming air pollutants. There are several types of fuel cells: polymer electrolyte fuel cell (PEFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC) and alkaline fuel cell (AFC). Among these SOFCs are the most efficient and have various advantages such as flexibility in fuel, high reliability, simple balance of plant (BOP) and a long history. Therefore, SOFC technology is attracting much attention as a power plant and is now close to marketing as a combined heat and power generation system. From the beginning of SOFC development, many perovskite oxides have been used for SOFC components; for example,  $\text{LaMnO}_3$  based oxide for the cathode and  $\text{LaCrO}_3$  for the interconnect are the most well known materials for SOFCs. The 3 current SOFCs operate at temperatures higher than 1073 K. However, lowering the operating temperature of SOFCs is an important goal for further SOFC development. Reliability, durability and stability of the SOFCs could be greatly improved by decreasing their operating temperature. In addition, a lower operating temperature is also beneficial for shortening the startup time and decreasing energy loss from heat radiation. For this purpose, faster oxide ion conductors are required to replace the conventional  $\text{Y}_2\text{O}_3$  stabilized  $\text{ZrO}_2$  electrolyte. A new class of electrolytes such as  $\text{LaGaO}_3$  is considered to be highly useful for intermediate temperature SOFCs.

*Solid Oxide Fuel Cells* Radenka Maric, Gholamreza Mirshekari, 2020-12-08. *Solid Oxide Fuel Cells: From Fundamental Principles to Complete Systems* is a valuable resource for beginners, experienced researchers and developers of solid oxide fuel cells (SOFCs). It provides a fundamental understanding of SOFCs by covering the present state of the art as well as ongoing research and future challenges to be solved. It discusses current and future materials and provides an overview of development activities with a more general system approach toward fuel cell plant technology, including plant design and economics, industrial data and advances in technology. Provides an understanding of the operating principles of SOFCs. Discusses state of the art materials, technologies and processes. Includes a review of the current industry and lessons learned. Offers a more general system approach toward fuel cell plant technology, including plant design and economics of SOFC manufacture. Covers significant technical challenges that remain to be solved. Presents the status of government activities, industry and market. This book is aimed at electrochemists, batteries and fuel cell engineers, alternative energy scientists and professionals in materials science.

*Solid Oxide Fuel Cells 12 (SOFC-XII)* S. C. Singhal, K. Eguchi, 2011-04-25. This issue of ECS Transactions contains papers from the Twelfth International Symposium on Solid Oxide Fuel Cells (SOFC XII), a continuing biennial series of symposia. The papers deal with materials for cell components and fabrication methods for components and complete cells. Also contained are papers on cell electrochemical performance and its modelling, stacks and systems and prototype testing of SOFC demonstration units for different applications.

**Solid Oxide Fuel Cells IX** S. C. Singhal, 2005. **Fuel Cells in the Waste-to-Energy Chain** Stephen J. McPhail, Viviana Cigolotti, Angelo Moreno, 2012-01-05. As the availability of fossil fuels becomes more limited, the negative impact of their consumption becomes an increasingly relevant factor in our choices with regards to primary energy sources. The

exponentially increasing demand for energy is reflected in the mass generation of by products and waste flows which characterize current society's development and use of fossil sources. The potential for recoverable material and energy in these ever increasing refuse flows is huge even after the separation of hazardous constituent elements allowing safe and sustainable further exploitation of an otherwise wasted resource. *Fuel Cells in the Waste to Energy Chain* explores the concept of waste to energy through a 5 step process which reflects the stages during the transformation of refuse flows to a valuable commodity such as clean energy. By providing selected integrated alternatives to the current centralized wasteful fossil fuel based infrastructure *Fuel Cells in the Waste to Energy Chain* explores how the concept of waste to energy can be constructed and developed into a realistic solution. The entire spectrum of current and future energy problems is illuminated through the explanation of the operational integration and marketing implications of high efficiency technological solutions using the real context of developed regions such as Europe. Up to date reviews are provided on the status of technology and demonstration implementation and marketing perspectives. The detailed technological information and insight gathered from over twenty years of experience in the field makes *Fuel Cells in the Waste to Energy Chain* a valuable resource for all engineers and researchers in the fields of energy supply systems and waste conversion as well as providing a key reference for discussions by policy makers, marketing experts and industry developers working in energy supply and waste management.

*Functional Materials for Solid Oxide Fuel Cells: Processing, Microstructure and Performance* Moisés Rómolos Cesário, Daniel Araújo de Macedo, 2017-04-19. *Frontiers in Ceramic Science* highlights the importance of ceramics and their applications in different fields such as manufacturing, construction, engineering, energy and much more. Each volume of the series brings a themed focus on a specific topic with contributions from experts around the world. The series is essential reading for materials science researchers interested in current developments in ceramic manufacturing and applications. Solid Oxide Fuel Cells (SOFCs) have received great attention among researchers in the past few decades due to their high electrochemical energy conversion efficiency, environmental friendliness, fuel flexibility and wide range of applications. This volume is a contribution from renowned researchers in the scientific community interested in functional materials for SOFCs. Chapters in this volume emphasize the processing, microstructure and performance of electrolyte and electrode materials. Contributors review the main chemical and physical routes used to prepare ceramic composite materials and explain a variety of manufacturing techniques for electrode and electrolyte production and characterization. Readers will also find information about both symmetrical and single fuel cells. The book is a useful reference for students and professionals involved in SOFC research and development.

**Materials for Energy Conversion Devices** C. C. Sorrell, J. Nowotny, S. Sugihara, 2005-10-30. As the finite capacity and pollution problems of fossil fuels grow more pressing, new sources of more sustainable energy are being developed. *Materials for energy conversion devices* summarises the key research on new materials which can be used to generate clean and renewable energy or to help manage problems from existing energy

sources The book discusses the range of materials that can be used to harness and convert solar energy in particular including the properties of oxide materials and their use in producing hydrogen fuel It covers thermoelectric materials and devices for power generation ionic conductors and new types of fuel cell There are also chapters on the use of such materials in the immobilisation of nuclear waste and as electrochemical gas sensors for emission control With its distinguished editors and international team of contributors Materials for energy conversion devices is a standard reference for all those researching and developing a new generation of materials and technologies for our energy need Detailed coverage of solar energy and thermoelectric conversion Comprehensive survey of new developments in this exciting field Edited by leading experts in the field with contributions from an international team of authors Hydrogen Science and Engineering Detlef Stolten, Bernd Emonts, 2016-01-04 Authored by 50 top academic government and industry researchers this handbook explores mature evolving technologies for a clean economically viable alternative to non renewable energy In so doing it also discusses such broader topics as the environmental impact education safety and regulatory developments The text is all encompassing covering a wide range that includes hydrogen as an energy carrier hydrogen for storage of renewable energy and incorporating hydrogen technologies into existing technologies *Electrochemical Energy* Pei Kang Shen, Chao-Yang Wang, San Ping Jiang, Xueliang Sun, Jiujun Zhang, 2018-10-08 Electrochemical Energy Advanced Materials and Technologies covers the development of advanced materials and technologies for electrochemical energy conversion and storage The book was created by participants of the International Conference on Electrochemical Materials and Technologies for Clean Sustainable Energy ICES 2013 held in Guangzhou China and incorporates select papers presented at the conference More than 300 attendees from across the globe participated in ICES 2013 and gave presentations in six major themes Fuel cells and hydrogen energy Lithium batteries and advanced secondary batteries Green energy for a clean environment Photo Electrocatalysis Supercapacitors Electrochemical clean energy applications and markets Comprised of eight sections this book includes 25 chapters featuring highlights from the conference and covering every facet of synthesis characterization and performance evaluation of the advanced materials for electrochemical energy It thoroughly describes electrochemical energy conversion and storage technologies such as batteries fuel cells supercapacitors hydrogen generation and their associated materials The book contains a number of topics that include electrochemical processes materials components assembly and manufacturing and degradation mechanisms It also addresses challenges related to cost and performance provides varying perspectives and emphasizes existing and emerging solutions The result of a conference encouraging enhanced research collaboration among members of the electrochemical energy community Electrochemical Energy Advanced Materials and Technologies is dedicated to the development of advanced materials and technologies for electrochemical energy conversion and storage and details the technologies current achievements and future directions in the field Recent Trends in Fuel Cell Science and Technology S. Basu, 2007-10-20 Fuel cell science and technology is

evolving fast for the past two decades as it is thought to be an efficient way of transforming chemical energy of hydrogen rich compounds to electrical energy Although this idea of direct conversion of chemical energy to electrical energy was first demonstrated by Sir William Grove in 1839 using a fuel cell it was only in the middle of the twentieth century when Bacon's pioneering work led to the use of fuel cell in space missions The interest in commercialization of fuel cell for civilian use has caught up with government organizations and private corporations for the past decade on account of fluctuating oil prices and environmental concerns It is well known that the conventional fossil fuel which is a primary source of gasoline is not going to last more than a hundred years in the face of ever increasing demand in the developed and developing countries Although the reserves of natural gas coal and tar sands may last another two to three hundred years with the current rate of production their conversion is not efficient and pollution free Thus scientists all over the world have taken up fuel cell development work in their quest of solution to the energy crises looming largely on global population This book aims to script the present status of the rapidly developing field of fuel cell science and technology

**Encyclopedia of Electrochemical Power Sources** Jürgen Garche, Chris K. Dyer, Patrick T. Moseley, Zempachi Ogumi, David A. J. Rand, Bruno Scrosati, 2013-05-20 The Encyclopedia of Electrochemical Power Sources is a truly interdisciplinary reference for those working with batteries fuel cells electrolyzers supercapacitors and photo electrochemical cells With a focus on the environmental and economic impact of electrochemical power sources this five volume work consolidates coverage of the field and serves as an entry point to the literature for professionals and students alike Covers the main types of power sources including their operating principles systems materials and applications Serves as a primary source of information for electrochemists materials scientists energy technologists and engineers Incorporates nearly 350 articles with timely coverage of such topics as environmental and sustainability considerations

**Sustainable Economy: Corporate, Social And Environmental Responsibility** Raymond W Y Kao, 2010-01-13 This book explains how corporate social responsibility is linked to long term sustainability of an economy and that the activities of an organization should not be only for its self interest but must also be honed for the benefit of common good A major approach the book advocates is corporate decision makers in an organization should work towards earning the trust of stakeholders rather than focus on short term profitability It also emphasizes the importance of recognizing and rewarding the contribution and commitment by participants of an organization Written by academics and consultants this book will be of interest to academicians media professionals organizational participants entrepreneurs and general public a

*Ceramic Conductors* Maria Gazda, Aleksandra Mielewczyk-Gryń, 2019-05-24 This Special Issue of Crystals contains papers focusing on various properties of conducting ceramics Multiple aspects of both the research and application of this group of materials have been addressed Conducting ceramics are the wide group of mostly oxide materials which play crucial roles in various technical applications especially in the context of the harvesting and storage of energy Without ion conducting oxides such as yttria stabilized zirconia doped



ceria devices such as solid oxide fuel cells would not exist not to mention the wide group of other ion conductors which can be applied in batteries or even electrolyzers besides fuel cells The works published in this Special Issue tackle experimental results as well as general theoretical trends in the field of ceramic conductors or electroceramics as it is often referred to

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