



# Solid oxide fuel cell technology

Principles, performance and operations

Kevin Huang and John B. Goodenough

# Solid Oxide Fuel Cell Technology Principles

**Radenka Maric, Gholamreza Mirshekari**



## **Solid Oxide Fuel Cell Technology Principles:**

Solid Oxide Fuel Cell Technology K Huang, J B Goodenough, 2009-07-30 High temperature solid oxide fuel cell SOFC technology is a promising power generation option that features high electrical efficiency and low emissions of environmentally polluting gases such as CO<sub>2</sub> NO<sub>x</sub> and SO<sub>x</sub>. It is ideal for distributed stationary power generation applications where both high efficiency electricity and high quality heat are in strong demand. For the past few decades SOFC technology has attracted intense worldwide R D effort and along with polymer electrolyte membrane fuel cell PEMFC technology has undergone extensive commercialization development. This book presents a systematic and in depth narrative of the technology from the perspective of fundamentals providing comprehensive theoretical analysis and innovative characterization techniques for SOFC technology. The book initially deals with the basics and development of SOFC technology from cell materials to fundamental thermodynamics, electronic properties of solids and charged particle transport. This coverage is extended with a thorough analysis of such operational features as current flow and energy balance and on to voltage losses and electrical efficiency. Furthermore, the book also covers the important issues of fuel cell stability and durability with chapters on performance characterization, fuel processing and electrode poisoning. Finally, the book provides a comprehensive review for SOFC materials and fabrication techniques. A series of useful scientific appendices rounds off the book. Solid oxide fuel cell technology is a standard reference for all those researching this important field as well as those working in the power industry. Provides a comprehensive review of solid oxide fuel cells from history and design to chemistry and materials development. Presents analysis of operational features including current flow, energy balance, voltage losses and electrical efficiency. Explores fuel cell stability and durability with specific chapters examining performance characterization, fuel processing and electrode poisoning.

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.

*Dynamic Modeling and Predictive Control in Solid Oxide Fuel Cells* Biao Huang, Yutong Qi, A. K. M. Monjur Murshed, 2013-01-25 The high temperature solid oxide fuel cell

SOFC is identified as one of the leading fuel cell technology contenders to capture the energy market in years to come. However, in order to operate as an efficient energy generating system, the SOFC requires an appropriate control system which in turn requires a detailed modelling of process dynamics. Introducing state of the art dynamic modelling, estimation and control of SOFC systems, this book presents original modelling methods and brand new results as developed by the authors. With comprehensive coverage and bringing together many aspects of SOFC technology, it considers dynamic modelling through first principles and data based approaches and considers all aspects of control including modelling, system identification, state estimation, conventional and advanced control. Key features: Discusses both planar and tubular SOFC and detailed and simplified dynamic modelling for SOFC. Systematically describes single model and distributed models from cell level to system level. Provides parameters for all models developed for easy reference and reproducing of the results. All theories are illustrated through vivid fuel cell application examples such as state of the art unscented Kalman filter model, predictive control and system identification techniques to SOFC systems. The tutorial approach makes it perfect for learning the fundamentals of chemical engineering, system identification, state estimation and process control. It is suitable for graduate students in chemical, mechanical, power and electrical engineering, especially those in process control, process systems engineering, control systems or fuel cells. It will also aid researchers who need a reminder of the basics as well as an overview of current techniques in the dynamic modelling and control of SOFC.

*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

**Solid Oxide Fuel Cells** Meng Ni,Tim S. Zhao,2013-08-16 Solid oxide fuel cells SOFCs are promising electrochemical power generation devices that can convert chemical energy of a fuel into electricity in an efficient environmental friendly and quiet manner Due to their high operating temperature SOFCs feature fuel flexibility as internal reforming of hydrocarbon fuels and ammonia thermal cracking can be realized in SOFC anode This book presents an overview of the SOFC technology with a focus on the recent developments in new technologies and new ideas for addressing the key issues of SOFC development This book first introduces the fundamental principles of SOFCs and compares SOFC technology with conventional heat engines as well as low temperature fuel cells Then the latest developments in SOFC R D are reviewed and future directions are discussed Key issues related to SOFC performance improvement long term stability mathematical modelling as well as system integration control are addressed including material development infiltration technique for nano structured electrode fabrication focused ion beam scanning electron microscopy FIB SEM technique for microstructure reconstruction the Lattice Boltzmann Method LBM simulation at pore scale multi scale modelling SOFC integration with buildings and other cycles for stationary applications

**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

**Principles of Fuel Cells** Xianguo Li,2005-12-22 The book is engineering oriented and covers a large variety of topics ranging from fundamental principles to performance evaluation and applications It is written systematically and completely on the subject with a summary of state of the art fuel cell technology filling the need for a timely resource This is a unique book serving academic researchers engineers as well as people working in the fuel cell industry It is also of substantial interest to students engineers and scientists in mechanical engineering chemistry and chemical engineering electrochemistry materials science and engineering power generation and propulsion systems and

automobile engineering      **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

*Modeling, Design, Construction, and Operation of Power Generators with Solid Oxide Fuel Cells* Jakub Kupecki, 2018-04-10 The book summarizes the current state of the solid oxide fuel cell SOFC technology in power generation applications It describes the single cells SOFC stacks micro combined heat and power systems large scale stationary power generators and polygeneration units The principles of modeling simulation and controls of power systems with solid oxide fuel cells are presented and discussed Authors provide theoretical background of the technology followed by the essential insights into the integrated power systems Selected aspects of the design construction and operation of power units in range from single kilowatts to hundreds of kilowatts are presented Finally the book reports the selected studies on prototype systems which have been constructed in Europe The book discusses the theoretical and practical aspects of operation of power generators with solid oxide fuel cells including fabrication of cells design of stacks system modeling simulation of stationary and non stationary operation of systems fuel preparation and controls      *Dynamic Modelling and Predictive Control in Solid Oxide Fuel Cells* Biao Huang, 2013 A timely treatment of the modeling and advanced control of the most promising fuel cell technology SOFC solid oxide fuel cells from cell to system level Dynamic Modeling and Predictive Control in Solid Oxide Fuel Cells Delivers comprehensive coverage of SOFC dynamic models and modeling approach from first principles bringing together many aspects of SOFC technology in one book for the first time Provides parameters for all models developed for easy reference and reproducing of the results Discusses lumped model and distributed model from cell level to system level Applications to the state of the art unscented Kalman filter model predictive control and monitoring techniques to SOFC systems Uses NMPC which is well understood by both industry and academia Essential reading for Graduate students and researchers in the area of fuel cells process systems engineering control systems engineering process control and electrochemical engineering      **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 *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 *Proceedings of the Fourth International Symposium on Solid Oxide Fuel Cells (SOFC-IV)* M. Dokiya, 1995 *Fuel Cells* B. Viswanathan, M. Aulice Scibioh, 2007 The book is a comprehensive reference book explaining concepts and their applications The interdisciplinary approach that draws on and clarifies the most recent research trends makes this book interesting to everyone who is concerned with energy demands and fuel cells Jacket **Fuel Cell Fundamentals** Ryan O'Hayre, Suk-Won Cha, Whitney Colella, Fritz B. Prinz, 2016-04-13 A complete up to date introductory guide to fuel cell technology and application Fuel Cell Fundamentals provides a thorough introduction to the principles and practicalities behind fuel cell technology Beginning with the underlying concepts the discussion explores fuel cell thermodynamics kinetics transport and modeling before moving into the application side with guidance on system types and design performance costs and environmental impact This new third edition has been updated with the latest technological advances and relevant calculations and enhanced chapters on advanced fuel cell design and electrochemical and hydrogen energy systems Worked problems illustrations and application examples throughout lend a real world perspective and end of chapter review questions and mathematical problems reinforce the material learned Fuel cells produce more electricity than batteries or combustion engines with far fewer emissions This book is the essential introduction to the technology that makes this possible and the physical processes behind this cost saving and environmentally friendly energy source Understand the basic principles of fuel cell physics Compare the applications performance and costs of different systems Master the calculations

associated with the latest fuel cell technology Learn the considerations involved in system selection and design As more and more nations turn to fuel cell commercialization amidst advancing technology and dropping deployment costs global stationary fuel cell revenue is expected to grow from 1.4 billion to 40.0 billion by 2022 The sector is forecasted to explode and there will be a tremendous demand for high level qualified workers with advanced skills and knowledge of fuel cell technology Fuel Cell Fundamentals is the essential first step toward joining the new energy revolution

**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 Modeling and Control of Fuel Cells M. H. Nehrir, C. Wang, 2009-03-11 The only book available on fuel cell modeling and control with distributed power generation applications The emerging fuel cell FC technology is growing rapidly in its applications from small scale portable electronics to large scale power generation This book gives students engineers and scientists a solid understanding of the FC dynamic modeling and controller design to adapt FCs to particular applications in distributed power generation The book begins with a fascinating introduction to the subject including a brief history of the U S electric utility formation and restructuring Next it provides coverage of power deregulation and distributed generation DG DG types fuel cell DGs and the hydrogen economy Building on that foundation it covers Principle operations of fuel cells Dynamic modeling and simulation of PEM and solid oxide fuel cells Principle operations and modeling of electrolyzers Power electronic interfacing circuits for fuel cell applications Control of grid connected and stand alone fuel cell power generation systems Hybrid fuel cell based energy system case studies Present challenges and the future of fuel cells MATLAB SIMULINK based models and their applications are available via a companion Web site Modeling and Control of Fuel Cells is an excellent reference book for students and professionals in electrical chemical and mechanical engineering and scientists working in the FC area *Modeling Solid Oxide Fuel Cells* Roberto Bove, S. Ubertini, 2008-04-20 This book fills the need for a practical reference for all scientists and graduate students who are seeking to define a mathematical model for Solid Oxide Fuel Cell SOFC simulation Structured in two parts part one presents the basic theory and the general equations describing SOFC operation phenomena Part two deals with the application of the theory to practical examples where different SOFC geometries configurations and different phenomena are analyzed in detail Science and Technology of Ceramic Fuel Cells N.Q. Minh, T. Takahashi, 1995-08-15 Ceramic fuel cells commonly known as



solid oxide fuel cells SOFCs have been under development for a broad range of electric power generation applications The most attractive feature of the SOFC is its clean and efficient production of electricity from a variety of fuels The SOFC has the potential to be manufactured and operated cost effectively The widening interest in this technology thus arises from the continuing need to develop cleaner and more efficient means of converting energy sources into useful forms This topical book provides a comprehensive treatise on solid oxide fuel cells and succeeds successfully in filling the gap in the market for a reference book in this field Directed towards scientists engineers and technical managers working with SOFCs as well as ceramic devices based on conducting materials and in related fields the book will also be invaluable as a textbook for science and engineering courses      **Fuel Cell Handbook (Sixth Edition) ,**

Uncover the mysteries within Explore with is enigmatic creation, **Solid Oxide Fuel Cell Technology Principles** . This downloadable ebook, shrouded in suspense, is available in a PDF format ( Download in PDF: \*). Dive into a world of uncertainty and anticipation. Download now to unravel the secrets hidden within the pages.

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