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"Nanostructured Materials for Next-Generation Energy Storage and Conversion: Fuel Cells"

Edited by Fan Li (Beijing Key Laboratory for Catalysis and Separation, Department of Chemistry and Chemical Engineering, College of Environmental and Energy Engineering, Beijing University of Technology, China), Sajid Bashir (Department of Chemistry, Texas A&M University-Kingsville, USA), Jingbo Louise Liu (Department of Chemistry, Texas A&M University-Kingsville, USA), Springer-Verlag GmbH Germany, part of Springer Nature, Berlin Heidelberg, Germany, 2018, 556 pages, ISBN: 978-3-662-56363-2, £229.99, €282.48, US$299.00

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Introduction

This Springer volume focuses on the design, characteristics and development potential of proton exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) technologies for both stationary and portable applications. The contents are organised into three themes: (a) energy policy and electrical power (Chapters 1–3); (b) optimisation of fuel cells (FCs) through design and synthesis of novel catalysts (Chapters 4–8); (c) optimisation of FCs through modelling and simulation (Chapters 9–18). The book forms a useful compendium of research activities across the globe that gives the reader a general overview rather than an in-depth treatment of any one area. The layout and presentation are of the usual Springer high standard with clearly visible graphs and illustrations; the book was compiled in 2018.

Energy Policy and Electrical Power

Chapter 1, 'Fuel Cell Technology: Policy, Features, and Applications – A Mini-Review' by S. Bashir (Texas A&M University-Kingsville, USA) *et al.*, starts with a comparative analysis of the energy policies of presidents Eisenhower and Trump with lots of facts and figures regarding historical energy use and energy vector types. The text covering fuel cells is PEM-centric (no SOFC or phosphoric acid fuel cell (PAFC)) and battery vehicles are not included in the discussion.

Chapter 2, 'Concept of Hydrogen Redox Electric Power and Hydrogen Energy Generators' by K. Ono (Kyoto University, Japan), argues that particular bipolar electrode configurations and power supply arrangements in coupled electrolyser or FC systems can improve overall efficiencies markedly over existing setups. Ono maintains one can treat the system as a combination of electrostatic energy and electrical to chemical energy conversion. I found the reasoning difficult to follow, perhaps because there are considerable conceptual challenges faced in dealing with electrostatic terms in highly condensed phases (see e.g. (1)). Unfortunately, no experimental data are presented to support the claims by Professor Ono.

Chapter 3, 'Evaluation of Cell Performance and Durability for Cathode Catalysts (Platinum Supported on Carbon Blacks or Conducting Ceramic Nanoparticles) During Simulated Fuel Cell Vehicle Operation: Start-Up/Shutdown Cycles and Load Cycles' by M. Uchida (University of Yamanashi, Japan) *et al.*, is a comprehensive work on the mechanistic details of degradation mechanisms and with proposed mitigation protocols. Different supports are looked at, not just carbon. We are reminded of the importance of understanding the practical challenges of stack design and operation

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in respect of membrane electrode assembly (MEA) degradation mechanisms. Degradation tests are based on voltammetric cycling to mimic start-up and shut-down automotive duty cycles. Perhaps not surprisingly, platinum dissolves and aggregates and carbon corrodes and different accelerated ageing protocols give different results. This is very important in the commercial world – you may not agree with the customers' tests, but they are the ones your product will be judged by!

Design and Synthesis of Novel Catalysts

Chapter 4, 'Metal Carbonyl Cluster Complexes as Electrocatalysts for PEM Fuel Cells' by J. Uribe-Godinez (Centro Nacional de Metrologia, Mexico) offers a general introduction and good summary of work in the field on catalysis preparation for PEMFC systems. Carbonyl complexes can be heat treated to produce metallic-like clusters and here the author looks at rhodium, iridium and osmium species with a heat-treatment regime up to 500°C in either nitrogen or hydrogen or thermolysed by redox in a suitable solvent. Unfortunately, there are no mass or specific surface area activity-based data so although a comparison with a 30 wt% Pt on XC72R catalyst is made, it is difficult to assess specific-area based catalytic activity.

Chapter 5, 'Non-Carbon Support Materials Used in Low-Temperature Fuel Cells' is written by X. Cao (Soochow University, China) *et al*. Traditional carbon supports used in FCs are prone to degradation through oxidation and many attempts have been made to find substitutes that can offer competitive performance, durability and cost. The authors give us a survey of the state-of-the-art. However, it is clear that carbon is favoured as a support (for good reason) and is unlikely to be substituted in the near term for low-temperature FCs.

Chapter 6, 'Noble Metal Electrocatalysts for Anode and Cathode in Polymer Electrolyte Fuel Cells' by S. Sharma and C. M. Branco (University of Birmingham, UK) is potentially a vast subject to tackle and the chapter covers the basics of what is understood about the performance-morphology related aspects of precious metal catalysts for PEMFC electrocatalysis. There is a particular emphasis on the oxygen reduction reaction (ORR).

Chapter 7, 'Nanomaterials in Proton Exchange Membrane Fuel Cells' is written by Y. Zhang (Harbin Institute of Technology, China) *et al*. In this chapter the PEM emphasis is a little more on direct methanol oxidation than the previous chapter and there is a shift of emphasis towards zero-dimensional, one-dimensional and two-dimensional materials. Carbon features explicitly in the form of nanotubes and graphene.

Chapter 8, 'Nanostructured Electrodes for High-Performing Solid Oxide Fuel Cells' by H. Ding (Colorado School of Mines, USA), reviews solution-based, ion infiltration methods of catalysing surfaces in electrode structures. Solution impregnation is well-known in the catalysis industries in general and it is no surprise that it has been adopted with enthusiasm by the SOFC research and development community. Much of the know how has been developed through traditional empirical methods and this chapter reviews progress in the field for a wide variety of catalysts from base and precious metals to complex oxides.

Modelling and Simulation

Chapter 9, 'Modelling Analysis for Species, Pressure, and Temperature Regulation in Proton Exchange Membrane Fuel Cells' is written by Z. Wang (Texas A&M University-Kingsville, USA). The model emphasis is on understanding the controlling factors in flooding of the MEA under steady-state conditions. The construction of the conservation equations for momentum, mass, species, charge and energy are given in some detail.

In Chapter 10, 'The Application of Computational Thermodynamics to the Cathode-Electrolyte in Solid Oxide Fuel Cells' by S. Darvish and M. Asadikiya (Florida International University, USA), the authors use the calculation of phase diagrams (CALPHAD) modelling approach with an emphasis on perovskite and fluorite structural motifs. A comprehensive summary of the materials challenge for SOFC materials when used as electrolytes and cathodes is presented. Complexity is added wherein multiple phases can form due to reaction of the components with gaseous impurities either in the air supply or through, for example, carbon dioxide cross-over from the anode. The CALPHAD approach allows for a workable description of the important defect chemistry of the complex oxides to be predicted together with ionic and electronic conductivities.

In Chapter 11, 'Application of DFT Methods to Investigate Activity and Stability of Oxygen Reduction Reaction Electrocatalysts' by X. Chen (Southwest Petroleum University, China) *et al*., the authors describe the use of density functional

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theory (DFT) to model and understand the behaviour of PEMFCs at the catalyst level with a focus on the ORR. Not surprisingly, the oxygen binding energy to (pure) metal surfaces is an activity descriptor of choice and its simplest exposition is in the well-known volcano plot which has platinum and palladium close to the apex. More sophisticated approaches consider the energetics of binding of the key intermediates and a mapping of the associated potential energy surface. As well as metallic-type catalysts, some metal-centred, macrocyclic moieties are also investigated for activity. Finally, the stabilities of these various types of ORR catalysts are considered.

Chapter 12, 'Hydrogen Fuel Cell as Range Extender in Electric Vehicle Powertrains: Fuel Optimization Strategies' is written by R. Álvarez and S. Corbera (Universidad Nebrija, Spain). As the title suggests, the purpose described in this chapter is to optimise strategies for combining battery and FC power units for range extension. There is a useful summary of the current 'competitive posturing' between the various proponents of battery and FC-powered vehicles. A MATLAB®/Simulink® vehicle model, coupled with the use of genetic algorithm routines, has been developed to examine the interplay of the electrical and mechanical components of the system over selected drive cycles. Importantly, the FC in this case study is used to maintain the charge of the lithium ion battery rather than as an alternative power source for coupling to the drive-train directly.

Chapter 13, 'Totalized Hydrogen Energy Utilization System' by H. Ito and A. Nakano (National Institute of Advanced Industrial Science and Technology (AIST), Japan) describes a hydrogen-based energy storage system utilising a reversible FC/electrolyser coupled with a metal hydride tank with fluctuating renewable electrical power inputs and heat and electrical power outputs (combined heat and power (CHP)). The heat flow from the system can be both positive and negative i.e. used for cooling or heating. The prototype demonstrator is a ten cell PEM-type stack with <1 kW output. The totalised hydrogen energy utilisation system (THEUS) was run continuously for three days on a fixed duty cycle and data collected and analysed.

Chapter 14, 'Influence of Air Impurities on the Performance of Nanostructured PEMFC Catalysts' by O. A. Baturina (Naval Research Laboratory, USA) *et al*., discusses the practical issues associated with using PEMFC units in the real world with different environments where air-borne pollutants or atmospheric conditions can pose a risk to the proper functioning and longevity of the PEMFC. An example shown is the dramatic and irreversible drop in cathode performance when exposed to low levels of compounds such as hydrogen chloride and bromomethane vapour. The various poisoning mechanisms are discussed together with possible mitigation strategies.

Chapter 15, 'Solid-State Materials for Hydrogen Storage' by R. Pedicini (Institute for Advanced Energy Technologies, Italy) *et al*., gives a general introductory review covering physisorption and chemisorption-based materials. The authors describe the often conflicting requirements that need to be met for a successful hydrogen storage material, such as the storage capacity, the kinetics of release and uptake and the resilience to mechanical degradation after many duty cycles. More novel, polymeric or inorganic hybrid materials are considered including polyether ether ketone-manganese dioxide (PEEK-MnO_2) composites and the use of more esoteric materials such as mixed metal oxides from volcanic ash.

In Chapter 16, 'Stress Distribution in PEM Fuel Cells: Traditional Materials and New Trends' by J. de la Cruz (CONACYT-INEEL, Mexico) *et al*., the authors remind us that as PEMFC stack technology advances, more attention needs to be focused on the mechanical and electrical engineering aspects of cell components such as the bipolar plates and membranes to optimise performance, manufacturability, durability and cost.

Chapter 17, 'Recent Progress on the Utilization of Nanomaterials in Microtubular Solid Oxide Fuel Cell' is written by M. H. Mohamed (Universiti Teknologi Malaysia) *et al*. Effective extension of the electrode-electrolyte-reactant interface in FCs presents material and electrode processing challenges. Micro-tubular SOFCs (MT-SOFCs) are a recent development for engineering porosity in the ceramic anode and cathode where the more traditional pore formers are substituted and supplemented using tailored hollow fibres. Inevitably, there is a compromise to be had in terms of ensuring good densification of materials to minimise ohmic drops while enabling reactant and product transport to function adequately at higher current densities. The authors present a brief review of progress in both medium and higher temperature SOFC systems.

Chapter 18, 'Nanostructured Materials for Advanced Energy Conversion and Storage Devices:

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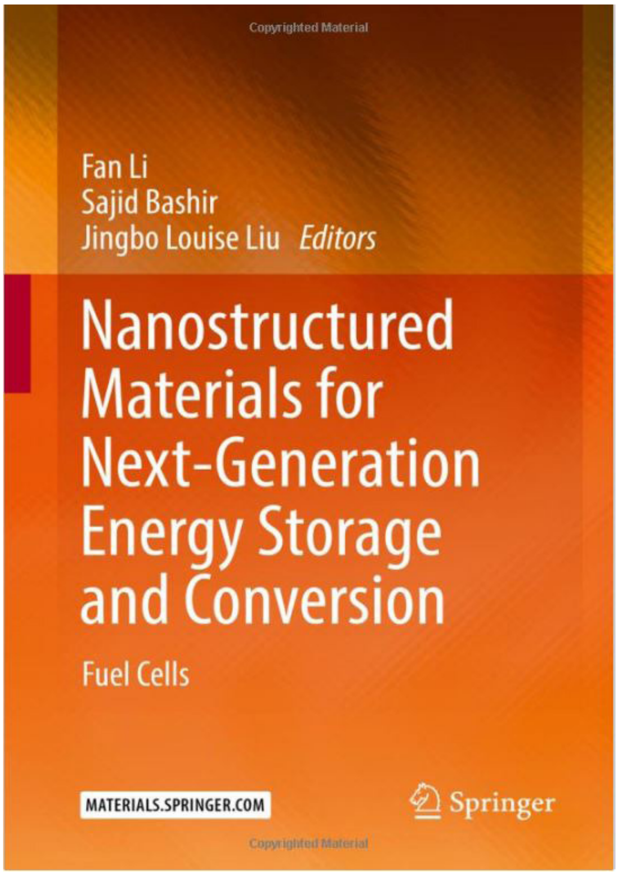
Safety Implications at End-of-Life Disposal' is written by S. Bashir (Texas A&M University-Kingsville, USA) *et al*. It is increasingly important for manufacturers to demonstrate that they have considered and mitigated against environmental damage that may arise from the disposal of products at end of life. The conclusion from this work using iron oxide nanoparticles as a test probe of materials entering the environment is that best practice should use a combination of life cycle assessment (LCA) and risk assessment (RA) methodologies.

Conclusion

In summary then, this volume brings together an interesting collection of articles covering mainly hydrogen PEM and SOFC technologies that will help build a more balanced understanding of the commercialisation and technical challenges arising from catalyst behaviour through to stack design.



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The Reviewer

Rob Potter worked for Johnson Matthey, UK, for over thirty years on a range of topics including fuel cells, solar cells, photoelectrocatalysis and thermoelectrics, before retiring in July 2019. He completed his PhD in electrochemistry at the University of Southampton, UK, in 1986.

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