"Fuel Cell Science and Engineering: Materials, Processes, Systems and Technology"

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Introduction

"Fuel Cell Science and Engineering: Materials, Processes, Systems and Technology" is a very comprehensive review of the current status of this technology. The book's editors, Detlef Stolten and Bernd Emonts of the Institute of Energy and Climate Research at Forschungcentrum Jülich GmbH, Germany, have a long history of working in the field of fuel cell research. Professor Detlef Stolten is the Director of the Institute of Energy Research – Fuel Cells at the Research Centre Jülich, Germany, and received his doctorate from the University of Technology at Clausthal, Germany. He served many years as a Research Scientist in the laboratories of Robert Bosch and Daimler Benz/Dornier. Professor Stolten's research focuses on electrochemical energy engineering including electrochemistry and energy process engineering of electrolysis, solid oxide fuel cell (SOFC) and polymer electrolyte fuel cell (PEFC) systems. Bernd Emonts is the Deputy Director of the Institute of Energy Research at the Jülich Research Centre, Germany. He was awarded his PhD on the fundamentals of mechanical engineering from RWTH Aachen University, Germany, in 1989. Emonts has been involved in extensive research and development projects in the areas of catalytic combustion and energy systems with low-temperature fuel cells and has published extensively in the field of fuel cells.

The present book is divided into eight sections that cover virtually all aspects of the current research effort in fuel cells, beginning with reviews of the various fuel cell technologies themselves, followed by sections on materials and manufacturing issues, diagnostics, quality assurance, modelling and simulation, balance of plant design and components, system demonstrations and market introduction, and finally knowledge distribution and public awareness.

There are 71 contributing authors, 20 of these being colleagues from the editors' research centre at Jülich. Other contributors include representatives from other German laboratories, US Department of Energy (DOE) laboratories, and a number of academic institutions from the Western Hemisphere. There is however a notable lack of contributions from Japan and Korea, both key centres of hydrogen and fuel cell research.

Platinum Group Metal Catalysts

Platinum group metals (pgms) are mentioned sporadically throughout the entire book. For example platinum catalyst loadings are mentioned four times in Chapter 1, 'Technical Advancement of Fuel-Cell Research and Development' by Bernd Emonts and colleagues. The first mention is to inform the reader that direct methanol fuel cells (DMFCs) have Pt catalyst loadings of 4 to 16 mg cm^{-2}. Later we are told that a specific DMFC light traction vehicle (for example, a go-cart) required >11 mg cm^{-2} and has been demonstrated in Germany. On a more promising note, Daimler already has, and General Motors (GM) aims to achieve by 2013, a per vehicle Pt catalyst requirement of 30 g. In the conclusion of this chapter the minimum loading for a DMFC of 4 mg cm^{-2} is deemed to be a significant barrier to commercialisation and the 30 g per vehicle statistic is seen as being extremely promising.

The pgms are mentioned next in Chapter 4, 'Alkaline Fuel Cells' by Erich Gülzow (German Aerospace Center (DLR), Stuttgart, Germany), but only to say they are good but that porous nickel can be used instead of Pt for terrestrial applications. Pt, however, is the best choice for use in space applications.

In Chapter 7 on 'Micro-Reactors for Fuel Processing' by Gunther Kolb (Institut für Mikrotechnik Mainz GmbH (IMM), Germany), platinum and palladium are both mentioned as alternatives to copper-zinc oxide for methanol steam reforming. Several of the references for this chapter deal with rhodium-based catalysts for fuel processing but this pgm is not mentioned in the text of the chapter.

In Chapter 8, on 'Regenerative Fuel Cells', by Martin Müller (Forschungszentrum Jülich GmbH, IEK-3, Germany) the catalysts for polymer electrolyte membrane (PEM) electrolysers cover the entire span of pgms. Pt is considered the best choice for hydrogen evolution. For the oxygen evolution reaction the order of catalytic activity is: iridium/ruthenium > iridium > rhodium > platinum. For a unitised regenerative polymer electrolyte membrane fuel cell (PEMFC) the catalyst of choice for the oxygen electrode is a Pt/Ir blend with Pt coated Ir oxide being mentioned as a promising concept.

Platinum Alloys

In Chapter 14 on 'Nanostructured Materials for Fuel Cells' by John F. Elter (Sustainable Systems LLC and University of Albany, State University of New York, USA) delves into the area of Pt alloys with discussion of Pt-Ru, platinum-tin and platinum-cobalt. The classic volcano plot showing that Pt provides a maximum current density for the hydrogen evolution reaction provides an interesting picture of how the pgms rate for this benchmark electrochemical reaction. Later in this chapter a very interesting figure is provided showing how activity is influenced by the relationship between oxygen binding energy and hydroxyl binding energy (**Figure 1**) (1). This leads into a very interesting discussion on Pt_3M alloys, where M = nickel, cobalt, iron, vanadium or titanium, that reviews the work of Markovic and coworkers (2). This prefaces the perhaps even more intriguing description of the core–shell catalysts developed by Adzic and coworkers (3). The shell is Pt on a Pd or Pd_3Co core.

The discussion of pgms continues with a section on the nanostructured thin film (NSTF) electrode that is being developed by 3M, who claim that they can achieve a total pgm content of less than 0.18 mg_{Pt} kW^{-1} (this would be approximately 9 g of Pt for a 50 kW automobile engine if it were a practical electrode). Furthermore, 3M believe that they can meet the elusive mass current density target set by the US DOE of 0.44 A mg_{Pt}^{-1} by using a Pt_3Ni_7 alloy. Other work being done on using Pt-NSTFs on various oxide whisker supports is also promising in terms of reducing catalyst costs for PEMFCs.

Materials and Manufacturing

Chapter 15, 'Catalysis in Low Temperature Fuel Cells – an Overview', by Sabine Schimpf and Michael Bron (Martin-Luther-Universität, Halle-Wittenberg, Germany), completes the section on materials and manufacturing. They provide a review of Pt-based catalysts including a volcano plot of the Pt_3M alloys (4) discussed in Chapter 14 by Elter. The core–shell work is also reviewed. There are interesting discussions on non-pgm catalysts and Pt-free noble metal catalysts. The main conclusions are that non-pgms cannot compete with Pt and that Pd-Co and Pd-V alloys were of similar activity to Pt.

This chapter also opens the topic of electrocatalyst degradation. Catalyst ripening (or particle-size

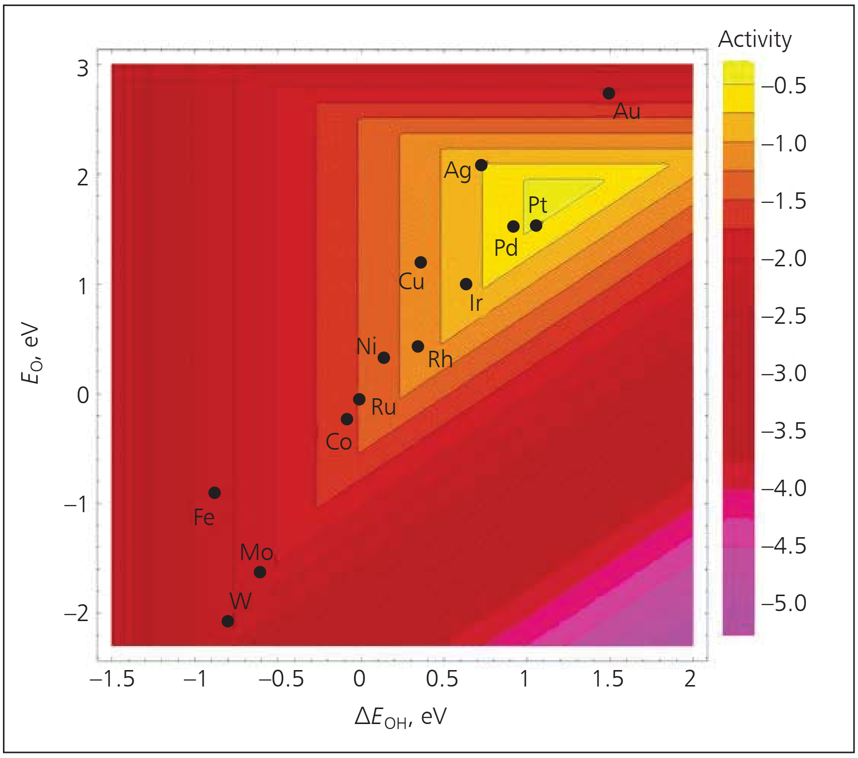


Fig. 1. Trends in oxygen reduction activity plotted as a function of both the O and OH binding energy (1)

growth) is mentioned but the topic of catalyst support corrosion is given more attention. Intriguingly, this chapter also covers the area of catalysts for hydrogen production but in a relatively superficial way. Ni, Pt, Pd, Rh and Ru are listed as being suitable catalysts for steam reforming, partial oxidation and autothermal reforming of hydrocarbons.

Catalyst Degradation

Chapter 20, 'Degradation Caused by Dynamic Operation and Starvation Conditions', by Jan Hendrik Ohs, Ulrich S. Sauter and Sebastian Maass (Robert Bosch GmbH, Germany) provides insights into Pt catalyst degradation in PEMFC electrodes. There is an interesting comparison of the Pourbaix diagrams of carbon and Pt. The oxidation of Pt is clearly visible for potentials above 0.8 V but clearly the corrosion of C is problematic over a much wider operating range of potential. The possibility of Pt leaving the electrode structure as Pt^{2+} ions that are then precipitated in an isolated and inactive band within the membrane is described as 'catalyst islanding'.

Chapter 30, 'Modeling of Polymer Electrolyte Membrane Fuel-Cell Components', by Yun Wang (University of California, Irvine, USA) and Ken S. Chen (Sandia National Laboratories, Livermore, USA), examines the use of high-fidelity modelling of the catalyst layer to optimise the composition in terms of pore structure and proportions of Pt, C and ionomer.

Chapter 35, 'Design Criteria and Components for Fuel Cell Powertrains', by Lutz Eckstein and Bruno Gnörich (RWTH Aachen University, Germany) provides a very detailed overview of the design options for fuel cell power trains. Several interesting statistics are cited. Firstly, that for 500,000 units per year production, fuel cell systems could be produced for 67 €/kW of which 42 €/kW is associated with the fuel cell stack and 17% of the total system cost is for Pt. This is further put into perspective by comparing a conventional internal combustion engine (ICE) 90 kW drivetrain cost of €800 *versus* €13,594 for the PEMFC equivalent.

Fuel Cell Markets

The penultimate section on System Verification and Market Introduction, Chapters 37 and 38 'Off-Grid Power Supply and Premium Power Generation' by Kerry-Ann Adamson (Pike Research – Cleantech Market Intelligence, UK) and 'Demonstration Projects and Market Introduction' by Kristin Deason (NOW

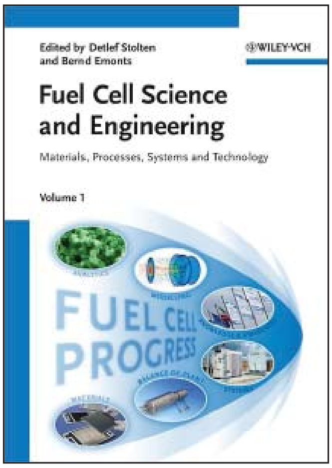
GmbH, Germany), provides encouraging reviews of successful demonstrations and promising markets.

The final section on Knowledge Distribution and Public Awareness is a useful supplement to the purely technical content. It includes a survey of current national and international organisations promoting hydrogen and fuel cells along with a short commentary on the need to increase efforts to educate the public about hydrogen as a fuel.

Summary

The book, "Fuel Cell Science and Engineering: Materials, Processes, Systems and Technology", is a very informative reference regarding the current progress in a very wide range of topics in fuel cell research and development. There is some duplication within the various chapters and many chapters begin with the standard description of what a fuel cell is and how it is a clean electrochemical energy conversion device. As can be seen from the above review, only nine of the forty-one chapters speak directly to the issue of pgm usage in fuel cells and fuel cell systems. Chapter 14, in particular, does an excellent job of reviewing the very interesting developments in reducing Pt loading using alloys and nano-structures. A considerable amount of the book is devoted to SOFC development that has little relevance to pgm except perhaps with respect to recent hydrocarbon reforming catalysts using Rh and other pgms although this work was not well covered. Overall, however, the book does indicate that there is reason to be optimistic regarding the potential for fuel cell automobiles to compete with current battery electric vehicles in the near future.

For researchers who already have some history with fuel cells and want to maintain their knowledge of the general progress of fuel cell research this could be a useful addition to one's personal library. For those specifically interested in pgm catalysis for fuel cells, I would recommend the book "Catalysis in Electrochemistry: From Fundamentals to Strategies for Fuel Cell Development" (5).



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The Reviewer

Brant A. Peppley is the Director of the Queen's-RMC Fuel Cell Research Centre and has been working in the field of fuel cell research for more than 26 years. His current research activities include modelling of PEMFCs, the development of new materials and fabrication technologies for fuel cell system components and the development of catalyst-coated heat transfer components for fuel processing systems.

